



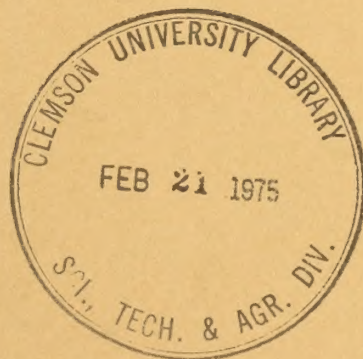
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Estimation Of Needle Populations

on Young, Open-Grown
Douglas-Fir by
Regression and
Life Table Analysis

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ABSTRACT

Needle populations of young, open-grown Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) can be estimated from regressions on tree height, stem diameter, crown width, number of limbs, number of branch tips, and foliated branch surface. A time-specific life table based on tree height and age appeared to realistically describe needle distributions by ages throughout the crown. The model also permitted evaluation of needle recruitment and loss for each tree age. In 13 years, the modeled tree recruited some 1.7 million needles and lost about 0.5 million needles to old age and the effects of extrinsic factors.

KEYWORDS: Douglas-fir, *Pseudotsuga menziesii*, foliage area.

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INTRODUCTION

Knowledge of a tree's leaf population and dynamics of leaf recruitment and loss is often needed for sampling pest populations and evaluating their impact on the host. To fill this need for young Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), a foliage study was made in 1969 and 1970 on 40 seedling- and sapling-sized trees growing in 8 localities in Oregon and Washington.

The first objective of the study was to develop methods for estimating needle populations on whole trees and to relate that data to some of the common foliage units involved in sampling for insect populations. Papers consulted were those by Buchanan (1936), Kittredge (1944), and Whittaker and Woodwell (1968).

The second objective was to derive a realistic model for simulating annual needle recruitment, aging, and mortality on the whole tree. Madgwick (1968) proposed a crown model for red pine (*Pinus resinosa* Ait.) based on leader growth and amount of foliage in the topmost whorl. This paper presents a model in life table format.

The purpose of a life table is to simulate life history by recording populations from birth to death. The first life tables were employed by actuarial companies and later by entomologists and other animal biologists (Deevey 1947, Morris and Miller 1954, Harcourt 1969). Life tables have also been suggested for evaluating changes in plant numbers (Harcourt 1970, Waters 1969). The model most often used by entomologists is keyed to discrete generations in which a single cohort is followed through a specific aging period (age-specific life table). The model presented in this paper more closely resembles the one used by demographers and

actuaries--that is, it deals with overlapping generations and is therefore keyed to specific time periods or anniversaries (time-specific life table).

METHODS AND PROCEDURES

Data were collected in mid-August and early September, after new growth had matured but before significant winter needle fall occurred. Study localities were near Randle (Woods Creek) in Washington and near Estacada (Fish Creek), Mill City (Green Basin), Upper Soda (Sheep Creek), Blue River (H. J. Andrews Experimental Forest), Tillamook (Kilchis River), Otis (Cascade Head Experimental Forest), and Corvallis (Mary's Peak) in Oregon. Median site index of the study areas was 116 (King 1966). Lowest site index was 106 at Estacada; highest was 142 at Tillamook.

Five open-grown, normal-appearing trees, ranging from 1.5 to 20 feet (0.46 to 6.1 m) tall were selected for foliage analysis at each locality. Each tree was cut and measured for height, age, stem diameter at ground level, width of crown at the widest point, and number of limbs. Starting at the bottom of the tree and working spirally up the stem, every fourth branch (nodal and internodal) was removed on trees taller than 2 feet (0.6 m) and measured for green weight, number of tips (fig. 1), and foliated area.^{1/} Every branch was taken on trees 2 feet (0.6 m) or less tall.

Foliage was clipped in the field from each branch and bagged according to whether the needles were from current

^{1/} Foliated branch surface is the area of the branch occupied by foliage and originates from a sampling system devised by Morris (1955). It was determined by multiplying branch length by widest width and dividing by 2.

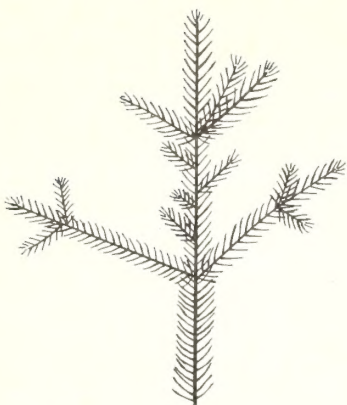


Figure 1.--Example of
3-year-old branch with
14 tips.

or older twigs and whether they came from the upper or lower half of the crown. Then, in the laboratory, the needles were dried, removed from the branches, weighed, and each bag proportionately subsampled for determination of needle populations in the various bags. These numbers were then expanded to get the total needle population for each tree.

The drying schedule for the foliage was air-drying for about 30 days at room temperature, then ovendrying for about 8 hours at 80° C. According to Forrest (1968), this means respiration during the prolonged air-drying period probably reduced the final ovendry weights by at least 8 percent. This was of no consequence in this study because the interest was needle numbers, not biomass. For those interested, the ovendry weights obtained are presented in appendix I.

Data were analyzed in a series of regressions in which the independent variables were:

- X_1 -- Crown width, measured in feet.
- X_2 -- Number of limbs on the tree, both nodal and internodal branches.
- X_3 -- Foliated branch area, meas-

ured in square feet, (see footnote 1).

- X_4 -- Number of branch tips on the tree or limb.
- X_5 -- Tree height, measured in feet.
- X_6 -- Tree age, determined by counting rings at the severed base.
- X_7 -- Stem diameter, measured in inches at ground level.

Dependent variables were old and new needles in one series of tests and number of limbs, foliated branch area, and number of branch tips in another series. Because covariance tests with all the independent variables revealed no significant differences in regressions among plots, the data from the eight study plots were pooled and each tree treated as an independent observation. A few trees were dropped from some analyses because of missing data for certain variables. Some regression equations were presented in log form (base 10) because of unequal variances encountered between upper and lower values of the independent variables.

RESULTS

FOLIAGE ESTIMATION ON TREES AND LIMBS

Several tree measurements correlated well in single variable equations with the number of needles on the tree (table 1). As indicated by the coefficients of determination (R^2), tree height, stem diameter, crown width, branch tips, and branch area accounted for about equal amounts of variation in needle populations on whole trees. Tree age with an R^2 of 0.62 gave a rather poor correlation, probably because of difficulty in accurately determining the true age of a tree. Frequent false rings, apparently due to numerous double flushes of growth in the early years, seemed to be the cause for the confusion.

The E -value in table 1 is the antilog of the standard error of the estimate (S.E.E.) for the regression and is called the "estimate of relative error" by Whittaker and Woodwell (1968). An E of 1.30 means that an estimation of y (thousands of needles) from any single tree measurement (x) is expected to fall within the range of $1.30 y$ to $y/1.30$ (67 percent of the time). Thus, in table 1, the best estimators of needle populations, from the standpoint of least error, are the equations with the smallest E -values.

The large number of needles annually added to a tree was notable. As shown in the arithmetic plots in figure 2, new needles accounted for more than half the total needle population on trees up to a height of about 10 feet (3.0 m). On taller trees, the difference widened, but the number of new needles was still close to 50 percent of the total needle population. At first glance, this suggests that the needle population on 3- to 20-foot (0.9- to 6.1-m) trees about doubles each year. Actually, because of mortality in the older age class of needles, this is true

for only a couple of years of growth. Annual needle recruitment and mortality are presented in more detail in the section on modeling needle populations.

Multiple regressions, combining seven independent variables in all possible combinations (Grosenbaugh 1967), improved correlations with the number of needles on a tree, but not enough to warrant the trouble of taking several measurements. The best equation had five independent variables and an R^2 of 0.99.

Trees between 1 and 2 feet (0.30 to 0.61 m) tall had 44 percent or more of their total foliage in the upper half of the crown. But as the trees became older and growth rate increased, the ratio dropped sharply until trees 10 feet (3.05 m) tall and taller had little more than 7 percent of their foliage in the upper half of the crown ($\text{Log } Y = 0.7113 + 0.0146 \left(\frac{100}{X}\right)$; $r^2 = 0.48$). At least 70 percent of those needles were new. There was a slight but significant negative correlation between tree height and the percent

Table 1.--Regression equations correlating old and new needles on seven independent variables associated with 1.5- to 20-foot (0.46- to 6.1-m) Douglas-firs ($n = 35$)

Variable		Regression equation (log base 10)	R^2	E
Y (thousands of needles)	X			
Total needles	Crown width	$\text{Log } Y = 0.8926 + 2.1101 \text{ Log } X_1$	0.94	1.43
Total needles	Limbs	$\text{Log } Y = -2.3456 + 2.3532 \text{ Log } X_2$	.84	1.78
Total needles	Branch area	$\text{Log } Y = 1.0165 + 0.4013 \text{ Log } X_3 + .1591 (\text{Log } X_3)^2$	.97	1.40
Total needles	Branch tips	$\text{Log } Y = -0.7888 + 0.9834 \text{ Log } X_4$	.98	1.23
Total needles	Height	$\text{Log } Y = 0.5011 + 1.9594 \text{ Log } X_5$	.95	1.38
Total needles	Age	$\text{Log } Y = -1.1897 + 3.7695 \text{ Log } X_6$	.62	2.47
Total needles	Stem diameter	$\text{Log } Y = 1.7513 + 1.8505 \text{ Log } X_7$	.96	1.34
New needles	Height	$\text{Log } Y = .4069 + 1.7491 \text{ Log } X_5$	.94	1.36

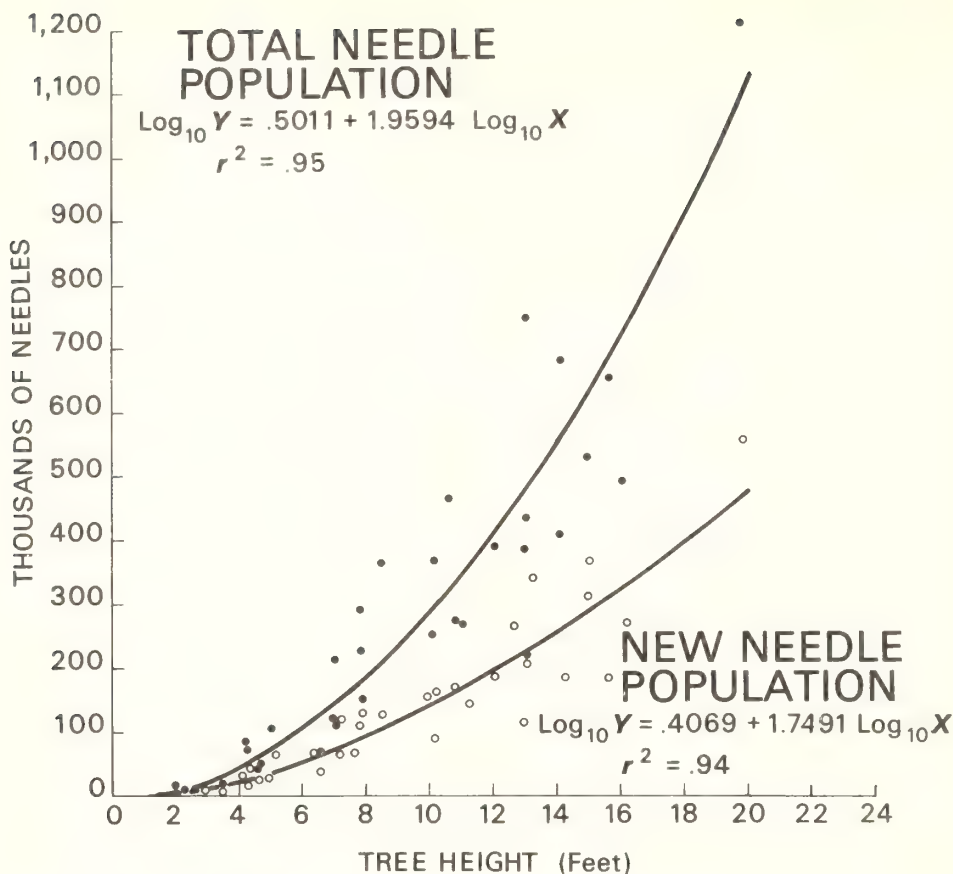


Figure 2.--Arithmetic plot of the log equations for total and new needle populations vs. tree height.

of new foliage in the upper crown ($Y = 93.94 - 0.73 X$); however, variation was great ($r^2 = 0.136$).

Correlations of tree height and stem diameter with number of limbs, foliated branch area, and branch tips on the tree are shown in table 2. All correlations had good R^2 values, though number of limbs appeared to have more variability than number of branch tips or foliated branch area.

The e in table 2 has the same function as E in table 1. It is presented in lower case in table 2 because it is derived and applied somewhat differently

for arithmetic equations than for log equations. Here, an e is derived by dividing the S.E.E. by the mean value of y (Whittaker and Woodwell 1968). An e -value of 0.20 suggests that a single estimate of y will fall within ± 20 percent of the equation's estimate of y (67 percent of the time).

Needle populations on branches exposed to the sun were well correlated with measurements of foliated branch area, green weight of the whole limb, and the number of branch tips. Data are summarized as regression equations in table 3. Data were not collected for correlations on shaded branches.

Table 2.--*Relationship between number of limbs, foliated branch area, and number of branch tips with tree height and stem diameter (n = 35)*

Dependent variable (Y)	Independent variable (X)	Regression equations	r^2	F
Number of limbs	Height	$Y = 25.171 + 7.864 X$	0.79	0.22
Number of limbs	Stem diameter	$Y = 27.341 + 31.505 X$	.80	.22
Foliated branch area	Height	$Y = -0.168 + 0.873 X + 0.887 X^2$	.89	.36
Foliated branch area	Stem diameter	$Y = -14.048 + 23.870 X + 10.055 X^2$	.94	.26
Number of branch tips	Height	$Y = -172.074 + 93.730 X + 13.421 X^2$	.91	.30
Number of branch tips	Stem diameter	$Y = -885.961 + 1364.092 X$	.88	.34

Table 3.--*Relationship between number of needles on whole limbs and three easily measured independent variables (n = 80)*

Independent variable	Regression equations (log base 10)	r^2	F
Green branch weight (g)	$\text{Log } Y = 2.3122 + 0.7623 \text{ Log } X$	0.94	1.53
Foliated branch area (ft ²) ^{1/}	$\text{Log } Y = 3.4924 + 0.9512 \text{ Log } X + 0.1820 (\text{Log } X)^2$	.91	1.48
Branch tips (number)	$\text{Log } Y = 2.5624 + 0.6027 \text{ Log } X + 0.0990 (\text{Log } X)^2$	.91	1.45

^{1/} Data apply only to branches exposed to the sun.

LIFE TABLE MODEL FOR EVALUATION OF NEEDLE DYNAMICS

Table 4 models the needle data of this study in life table form. Growth rate of the modeled tree (columns 1 and 2) is derived from the equation $\sqrt{\text{Height}} = 0.058 + 0.341 \text{ Age}$ (height in feet; age in years), the average growth rate of small Douglas-fir--up to 20 feet (6.1 m) tall--in stands rated site index

116.^{2/} Needle data in columns 3 and 4 were calculated from the two equations in figure 2.

^{2/} The growth equation curve was fitted to the restrictions stated by King (1966) that a tree from site index 116 should be about 4 feet (1.2 m) tall at age 6 and 20 feet (6.1 m) tall at age 13. A condition added by the author was that the tree should be 0.5 to 0.8 foot (0.15 - 0.24 m) tall at age 2. The equation for age in table 1 was rejected because of its low R^2 and because the tree's growth rate was not an accurate reflection of what was observed in the field.

Table 4.--Life table of needle populations on a Douglas-fir modeled to live 13 years on site index 116 with needles removed for senescence and loss due to extrinsic factors

Tree age (years)	Total height (feet)	Total needle population	Needle populations by age class					Needle loss		
			New	1-year-old	2-year-old	3-year-old	4-year-old	Senescence	Extrinsic factors	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	0.16	1/ 87	87	--	--	--	--	0	0	0
2	.54	1/ 956	869	87	--	--	--	0	0	0
3	1.17	4,312	3,358	867	87	--	--	0	2	2
4	2.02	12,572	8,728	3,009	777	58	--	22	446	468
5	3.11	29,282	18,565	7,575	2,611	506	25	223	1,632	1,855
6	4.43	58,560	34,475	15,772	6,435	1,163	215	931	4,266	5,197
7	5.98	105,414	58,264	29,076	13,302	4,070	702	2,655	8,755	11,410
8	7.76	175,630	91,897	49,104	24,505	8,409	1,715	6,062	15,619	21,681
9	9.78	276,375	137,753	77,874	41,611	15,574	3,563	12,045	24,963	37,008
10	12.03	414,667	197,833	117,309	66,317	26,577	6,631	21,753	37,788	59,541
11	14.51	598,687	274,600	169,541	100,533	42,625	11,388	36,498	54,082	90,580
12	17.22	837,336	370,510	237,015	146,335	65,080	18,396	57,833	74,028	131,861
13	20.17	1,141,563	488,540	322,681	206,419	95,583	28,340	87,520	96,793	184,313
Totals			1,685,479					225,542	318,374	543,916

^{1/} Eight needles added to avoid negative needle fall.

Although complicated in appearance and derivation, the general principle of this type of life table is easy to grasp. After the number of needles the tree recruits each year is established, all needles are aged annually at the time of bud burst by moving them one column to the right and one row downwards. For example, in table 4, a 1-year-old tree starts out with 87 new needles. Next year, those 87 needles are 1-year-old and live on a tree that is 2 years old. At the same time, the tree recruits 869 new needles at bud burst, making a total of 956 needles on a 2-year-old tree. The next year, the original 87 needles become 2 years old, the 869 needles 1 year old, and the 3-year-old tree recruits 3,358 new needles. At this point, the table becomes complicated because some of the needles start to die. Appendix II accounts for mortality and how the completed schedule shown in table 4 is generated. It is sufficient here to say that some assumptions were made on when needles die of old age. The most obvious assumption from inspection of table 4

was that needles live no longer than 5 years.^{3/}

The fate of a cohort of needles recruited by a tree in any one year is seen by following them diagonally from left to right down the table. For example, the 3,358 needles recruited on the 3-year-old tree drops to 3,009 needles when the tree becomes 1 year older. In the next 3 years, the population of that cohort drops to 2,611 needles, 1,163 needles, and finally 702 needles the year before they all die.

The age-class distribution of needles on any tree of a particular age can be determined by reading along the horizontal. In table 5, needle distribution, expressed

^{3/} The author checked on needle mortality on all 40 plot trees as well as many other young Douglas-fir. Only rarely could trees be found with more than 5 years of needles on them. However, 7 years of needles were frequently observed on older trees (particularly on shaded branches), which agrees with the findings of Silver (1962).

as a percentage of the total needle population, shows that the proportion of needles in the various age classes changes greatly as the tree grows older. This partly reflects both the tree's declining capacity to increase needle production and also a constantly increasing reservoir of older needles being retained in the crown. Theoretically each tree will ultimately reach an age when needle production will about

equal needle loss and the distribution of needles of different ages will stabilize.

As a partial check on the model, detailed foliage analyses were made of three young Douglas-firs growing on site index 116 land near Corvallis, Oregon. The age-class needle distribution on these trees (table 6) was rather close to that generated by the model in table 5.

Table 5.--Distribution of Douglas-fir needles within each age class expressed as a percent of the total needle population on trees of that age (derived from table 4)

Height (feet)	Tree age (years)	Total needle population	Distribution of needles in crown				
			New	1-year-old	2-year-old	3-year-old	4-year-old
<i>Number</i>			<i>Percent</i>				
0.16	1	87	100	--	--	--	--
.54	2	956 ^{1/}	90.9	9.1	--	--	--
1.17	3	4,312	77.9	20.1	2.0	--	--
2.02	4	12,572	69.4	23.9	6.2	0.5	--
3.11	5	29,282	63.4	25.9	8.9	1.7	0.1
4.43	6	58,560	58.9	26.9	11.0	2.8	.4
5.98	7	105,414	55.3	27.6	12.6	3.9	.6
7.76	8	175,630	52.3	27.9	14.0	4.8	1.0
9.78	9	276,375	49.8	28.2	15.1	5.6	1.3
12.03	10	414,667	47.7	28.3	16.0	6.4	1.6
14.51	11	598,687	45.9	28.3	16.8	7.1	1.9
17.22	12	837,336	44.2	28.3	17.5	7.8	2.2
20.17	13	1,141,563	42.8	28.2	18.1	8.4	2.5

^{1/} Eight needles added to avoid negative needle fall.

Table 6.--Actual needle distribution on three Douglas-firs from site index 116 land near Corvallis, Oregon

Height (feet)	Total needle population	Percent distribution of needles in crown				
		New	1-year-old	2-year-old	3-year-old	4-year-old
	<i>Number</i>	<i>Percent</i>				
6.0	83,140	51.5	24.7	19.0	4.5	0.3
9.8	318,809	50.6	25.3	19.0	4.7	.4
14.5	734,143	53.7	24.9	17.5	3.6	.3

Total needle production can be determined from table 4 for any given year up to age 13 by summing needle recruitment in column 4. For example, the model tree recruits 1,685,479 needles in its first 13 years, with about 68 percent of those needles still on the tree at the end of that period. Approximately 50 percent of all the needles recruited in 13 years stemmed from the last 2 years of growth--29 percent in the last year alone.

This appears to be a rapid increase, but in reality the tree is gradually slowing in its ability to recruit new needles. Table 7 shows how this pattern occurs. In this table, the number of tips on a tree is related to tree age (the first 3 years unreported since they extend beyond the field data). This relationship is examined because the reproductive capacity of tree foliage lies in the buds. Accordingly, an evaluation of tip production is a measure of the tree's capacity to increase needle numbers.

Annual tip production, the difference between any year's population and the population the year before ($N_t - N_{t-1}$), shows an impressive numerical increase in tips each year (table 7). What this reflects,

though, is the accumulative effects of prior tip multiplication. With Miller's (1965) technique of comparing tip production as a ratio of populations in adjacent years ($\frac{N_t}{N_{t-1}}$), it is found that the rate

of increase per tip declines steadily as the tree grows older. It shows that a tree between the ages of 4 and 5 produces 3.46 new tips for each single tip the year before. Thereafter, the rate declines. By the 13th year, the reproductive rate is 1.33 tips per year. This ratio is essentially the same as the net reproduction-rate (r_0) described by Andrewartha and Birch (1954).

DISCUSSION

Most of the regression equations developed in this study accounted for a sizable amount of variation in estimating needle populations on young Douglas-fir and should be of value to field workers concerned with sampling and pest impact studies. For unknown reasons, the needle populations were much higher than those reported for Douglas-fir growing in Switzerland (Burger 1935). Perhaps the Swiss trees were competing with others. It is emphasized that the data

Table 7.--Tip production as a measure of Douglas-fir's capacity to increase foliage

Tree age (years)	Tree height (feet)	Total tips on trees (N) ^{1/}	Annual tip recruitment ($N_t - N_{t-1}$)	Tip recruitment ratio $\frac{N_t}{N_{t-1}}$
4	2.02	72	--	--
5	3.11	249	177	3.46
6	4.43	507	258	2.04
7	5.98	868	361	1.71
8	7.76	1,363	495	1.57
9	9.78	2,028	665	1.49
10	12.03	2,898	870	1.43
11	14.51	4,001	1,103	1.38
12	17.22	5,422	1,421	1.35
13	20.19	7,191	1,769	1.33

^{1/} From the equation $y = -172.074 + 93.730 x + 13.421 x^2$ in table 2.

from this study apply only to open-grown trees. To estimate the number of needles per acre or per tree in situations where there is close competition among trees requires some evaluation of needle loss due to crowding.

It is also emphasized that the life table model presented in this paper is essentially a research hypothesis. Although the needle distribution generated compared favorably with three check trees, the mortality assumptions used to derive the distribution were based largely on observations rather than systematic study. Future research would require precise data on needle loss, with an accounting for the causes of needle mortality. For generalized conclusions and practicality in other research studies, the pertinent data should be obtained from trees on different sites and crown classes.

Basically, the life table format is a logical ledger in which to present needle data. Needles are recruited, age, and die just like other organisms for which life tables have been created. In fact, needle populations have unique characteristics which eliminate some of the more vexing problems associated with analyzing animal numbers by life tables. Needles have a distinct anniversary date, cohorts that can be followed rather closely, no problems with immigration and emigration, and no problems arising from changing sex ratios.

Most important, the analysis of needle life table data, in which the causes of mortality are identified and quantified, would provide much needed information on the relative importance of specific extrinsic factors, such as insects and diseases, as they relate to specific tree characteristics of growth, form, and appearance.

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APPENDIX I

Table 8.--*Mean oven-dry weights of 100 new and old needles in the upper and lower crowns of short and tall trees*

Portion of tree	Tree height	Weight of 100 new needles		Weight of 100 old needles	
		Mean	S.D.	Mean	S.D.
	<i>Feet</i>	<i>----- Grams -----</i>			
Upper half of crown	1-10	0.387 $\pm$ 0.091		0.437 $\pm$ 0.111	
	10-20	.503 $\pm$.077		.632 $\pm$.135	
Lower half of crown	1-10	.263 $\pm$.053		.350 $\pm$.057	
	10-20	.355 $\pm$.072		.457 $\pm$.056	

Significant differences ($P < 0.01$) were noted in the weights between old and new needles, between needles from the upper and lower crown, and between needles on tall and short trees. No interaction effects were noted.

APPENDIX II

The step-by-step details and assumptions involved in generating the life table shown in table 4 are as follows:

1. Establish growth rate for an average tree and record in columns 1 and 2. As described in the text, this was accomplished with the equation

$$\sqrt{\text{Height}} = 0.058 + 0.341 \text{ Age.}$$

2. Establish the total needle population for each tree height (equation in figure 2) and record in column 3.

3. Establish needle recruitment (new needle population) for each height of the tree (equation in figure 2) and record in column 4.

4. Establish needle mortality between anniversary dates (bud burst) by comparing the total needle population that could be on the tree with the actual population that exists. For example, the population on a 5-year-old tree could be all the needles that are on the tree at age 4 (12,572) plus the needles recruited at age 5 (18,565), making a total possible population of 31,137 needles. Since this is 1,855 more needles than the 29,282 needles actually existing on the 5-year-old tree, the difference must be needle mortality that occurred between the fourth and fifth anniversary dates. Needle loss is calculated in this way for each anniversary date and recorded in column 11.

5. Age the needles on each anniversary date and remove the needles that die. Starting with the first anniversary, the 87 needles recruited the first year are moved one column to the right and one row downwards. Thus, on the 2-year-old tree, there is a population of 869 newly recruited needles and 87 needles formed the year before. There is no mortality,

so no needles are removed. The next anniversary, the populations are again moved one column right and one row downward. But this year (3-year-old tree), 2 needles die (column 11) and must be removed to balance the population going into the third year. The removal of this mortality is recognition that needles die of old age or succumb to external factors of the environment, such as insects or disease. Accordingly, a death schedule must be established for senescence and mortality due to extrinsic factors. Working backwards, field observations showed that no needles survive to reach their fifth birthday. Also needle populations drop sharply between the third and fourth and second and third years. Less severe loss was observed in first- and second-year needles. Based on these observations, the following assumptions were established for removing dead needles: (a) new needles suffer no mortality; (b) senescence removes 25 percent of the needles aging from 2 to 3 years, 50 percent of the needles aging from 3 to 4 years, and all needles past the fourth year; (c) mortality not attributed to old age is designated as loss due to extrinsic factors and the needles are removed in proportion to the standing needle population in each age class.

6. Because the 3-year-old tree is not old enough to have needles die of old age, the two needles dying that year must be assigned to the impact of extrinsic factors (column 10). On a proportional basis, both are removed from the needle population reaching its first birthday, i.e., the 869 recruited on the 2-year-old tree becomes 867 needles on the 3-year-old tree. The next year, when the tree becomes 4 years old, 468 needles (column 11) must be removed. According to the assumptions on

senescence, the 87 needles passing from the second to the third year must lose 25 percent of its population (22 needles) due to old age. That leaves 446 needles (column 10) to be removed from the tree because of death by extrinsic factors. On a proportional basis, those 446 needles are removed thusly--349 needles from the population aging from new- to 1-year needles ($3,358 - 349 = 3,009$), 90 needles from the population aging from 1- to 2-year-old needles ($867 - 90 = 777$), and 7 needles from the population aging from 2- to 3-year-old needles ($65 - 7 = 58$), remembering that 22 needles were already removed from the original population of 87 needles for senescence. As in nature, the process is repeated year-by-year down the schedule until it is completed as in table 4. The important point to remember is that the mortality calculations require a form of double-entry accounting--mortality due to senescence is removed first; mortality from extrinsic factors removes what is left.

If the total impact of extrinsic factors on needle populations is needed, a

theoretical schedule can be generated which removes only the needles dying of old age. Table 9 shows the result of such a simulation. It shows, instead of 225,542 needles dying of old age in 13 years (table 4), 351,796 needles would have died of senescence if they had lived their full life span. Thus the real impact of intrinsic factors is not the 318,314 needle loss shown in table 4, but rather the difference between the total mortality in table 4, less the mortality due to senescence in the theoretical table ($543,916 - 351,796 = 192,120$).

It is likely that the life table format is also suitable for studying other aspects of tree production, such as limbs or roots. Total limbs (or the like) could be determined by regression techniques for each age of the tree. Then, as in table 7, annual production for time t can be calculated by the formula $N_t - N_{t-1}$. Thus a matrix for distribution of limbs can be generated by age classes as in table 4. This, in turn, presents a research outline for determining survival rates at all stages of tree maturity.

Table 9.--*Theoretical life table for recruiting and aging of needles on young Douglas-fir, assuming the only mortality is due to senescence*

Tree age (years)	Tree height (feet)	Theoretical total needle population	New needle population (recruitment)	Theoretical needle distribution				Needle loss (senescence)
				1-year-old	2-year-old	3-year-old	4-year-old	
1	0.16	87	87	--	--	--	--	0
2	.54	956 ^{1/}	869	87	--	--	--	0
3	1.17	4,314	3,358	869	87	--	--	0
4	2.02	13,020	8,728	3,358	869	65	--	22
5	3.11	31,336	18,565	8,728	3,358	652	33	249
6	4.43	64,613	34,475	18,565	8,728	2,519	326	1,198
7	5.98	119,110	58,264	34,475	18,565	6,546	1,260	3,767
8	7.76	201,833	91,897	58,264	34,475	13,924	3,273	9,174
9	9.78	320,732	137,753	91,897	58,264	25,856	6,962	18,854
10	12.03	484,109	197,833	137,753	91,897	43,698	12,928	34,456
11	14.51	700,958	274,600	197,833	137,753	68,923	21,849	57,751
12	17.22	980,720	370,510	274,600	197,833	103,315	34,462	90,748
13	20.17	1,333,683	488,540	370,510	274,600	148,375	51,658	135,577
Totals			1,685,479					351,796

^{1/} Eight needles added to avoid negative needle fall.

Mitchell, R. G.

1974. Estimation of needle populations on young, open-grown Douglas-fir by regression and life table analysis. USDA For. Serv. Res. Pap. PNW-181, 14 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Needle populations of young, open-grown Douglas-fir can be estimated from regressions based on several characteristics of tree form. A life table model permitted evaluation of needle recruitment and distribution for each age of tree.

Keywords: Douglas-fir, *Pseudotsuga menziesii*, foliage area.

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Tree age (years)	Tree h (feet)
1	0.
2	.
3	1.
4	2.
5	3.
6	4
7	5
8	7
9	9
10	12
11	14
12	17
13	20

Totals

^{1/} Eight ne

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

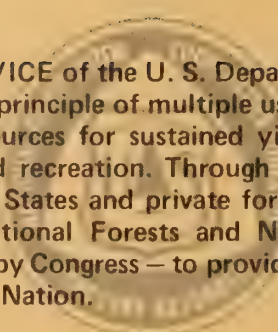
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INFLUENCE OF FERTILIZER NITROGEN SOURCE

***on deer browsing
and chemical composition
of nursery-grown Douglas-fir***



M. A. Radwan
G. L. Crouch
W. D. Ellis

ABSTRACT

Effects of nursery fertilization of year-old Douglas-fir seedlings with ammonium sulfate, calcium nitrate, and urea on browsing by black-tailed deer, and chemical properties were compared. Fertilizers were applied at 56 kg N/ha in May and again in September, and seedlings were harvested in November. Seedlings from the different treatments were equally browsed by penned deer. Chemical analyses of shoots indicated significant differences due to N source only in manganese and sulfur contents. However, the larger size of urea- and nitrate-fertilized plants indicated that their shoots contained higher quantities of the majority of the chemicals determined.

Keywords: Douglas-fir, *Pseudotsuga menziesii*, browse, deer, chemical analysis.

Expanding reforestation with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) requires intensive management of Pacific Northwest forest tree nurseries. In such management, fertilization, especially with nitrogen, is increasingly important. Although amounts of nitrogen applied by nurseries in the region are based upon the fertility of nursery soils, choice of nitrogen source has been largely empirical.

The form of nitrogen supply greatly affects both growth and chemical composition of conifer seedlings of several species (Pharis et al. 1964, Durzan and Steward 1967, McFee and Stone 1968, Christersson 1972). Such effects in nursery stock could substantially influence success of regeneration, especially if deer browsing preference for seedlings is changed by different fertilization regimes.

Information on effects of nitrogen sources on Douglas-fir seedlings is limited and contradictory. In British Columbia, seedlings showed greater growth response to ammonium than to nitrate in one study (van den Driessche 1971), but grew better with nitrate than with ammonium in another (Krajina et al. 1972). In western Washington, on the other hand, we recently found that seedling growth in the nursery and outplanting performance of trees fertilized with nitrate and urea were similar and superior to those of trees fertilized with ammonium (Radwan et al. 1971). In addition, there are no reports in the literature on effects of different forms of nitrogen on deer browsing preference for, or detailed chemical composition of, Douglas-fir seedlings.

This study, therefore, is a further investigation of effects of nursery fertilization of Douglas-fir with ammonium

sulfate, calcium nitrate, and urea on chemical properties and browsing preference by black-tailed deer (*Odocoileus hemionus columbianus*). We used seedlings from our earlier study (Radwan et al. 1971). Also, we limited chemical analysis to the tips of the seedlings since these are the tissues normally browsed by deer and because it is generally agreed that shoot tips provide a good basis for assessing the nutrient status of Douglas-fir.

MATERIALS AND METHODS

Douglas-fir seedlings were grown and fertilized at the Webster Nursery in western Washington as previously outlined (Radwan et al. 1971). Briefly, three fertilizers (ammonium sulfate, calcium nitrate, and urea) were applied to 1-year-old seedlings in nine beds. Design included three replications per treatment, with treatments assigned at random. Fertilizers were broadcast at 56 kg N/ha in May and again in September, and seedlings were harvested in November. To balance treatments as much as possible, seedlings of the ammonium sulfate and urea treatments received the assigned nitrogen fertilizer plus calcium sulfate containing calcium equivalent to that in the calcium nitrate treatment. At harvest, randomly selected trees from each treatment were lifted by hand and used for subsequent determinations of deer preference and chemical properties. At that time, shoots of seedlings from the calcium nitrate and urea treatments were significantly larger than those from the ammonium sulfate treatment (Radwan et al. 1971).

Deer preference was tested in a 1-ha enclosure located near the nursery and maintained by the U. S. Bureau of Sport Fisheries and Wildlife. During the test, the enclosure contained a stand of orchardgrass (*Dactylis glomerata*), commercial pelleted ration, and seven

black-tailed deer. Test seedlings, 100 from each treatment, were exposed to voluntary feeding by the deer in a randomized block design (Dodge et al. 1967). Treatments were replicated in 10 blocks, and seedlings were planted to uniform height at 1- by 1-m spacing within blocks. Inspections for browsing evidence were made daily until all test seedlings were browsed. A tree was considered browsed if any portion of it was removed by deer; only the first browsing was recorded. Relative preference was determined by comparing percent browsing among treatments periodically during the test and days of exposure required for complete browsing.

Chemical analyses for each replication were carried out in duplicate on tissues composited from 240 seedlings. Samples were taken by clipping the top 5 cm of the terminal and two lateral shoots of each seedling. The fresh tissue was chopped into small pieces and thoroughly mixed. Subsamples were taken for determination of moisture, pH, and titratable acidity. Remaining tissue was dried to constant weight at 65° C, ground to 40 mesh in a Wiley mill, and stored in sealed containers at -15° C until analyzed.

Moisture was determined by drying to constant weight at 65° C, and ash in the ground tissue was estimated in platinum crucibles at 500° to 550° C. Titratable acidity and pH were determined on centrifuged aqueous extracts of the fresh tissue by titration with standard alkali and use of a pH meter with a glass electrode (Horwitz 1970). Total available carbohydrates were extracted and hydrolyzed with 0.2 N H₂SO₄ (Smith et al. 1964) and resulting sugars were estimated as glucose (Hassid 1937). Analyses of other tissue components were made as follows: potassium and sodium by flame photometer, calcium by a titrimetric method, and total and

soluble nitrogen by micro-Kjeldahl procedure (Horwitz 1970); magnesium, iron, and manganese by the magnesium ammonium phosphate titrimetric method, O-phenanthroline colorimetric method, and the colorimetric periodate procedure, respectively (Chapman and Pratt 1961); phosphorus according to Fiske and Subbarow (1925); chlorine, as chloride, by a modification of the Volhard method (Caldwell and Moyer 1935); and sulfur by a turbidimetric technique modified from Butters and Chenery (1959).

STATISTICAL ANALYSIS

Data were subjected to analysis of variance, and means were separated according to Tukey's test as required (Snedecor 1961).

RESULTS AND DISCUSSION

Deer Preference

Browsing of test seedlings began almost immediately; but from the start, no pattern of preference among nitrogen sources was detected. Day-to-day tabulations showed one treatment ahead one day and behind the next. Analysis of variance at 5-day intervals similarly revealed no significant differences among treatments during the 30-day exposure period. Largest difference occurred at 10 days when cumulative browsing of seedlings from the ammonium sulfate, urea, and calcium nitrate treatments were 70, 76, and 68 percent, respectively. A second comparison, using the mean number of exposure days until all seedlings were browsed (Dimock 1971), also detected no significant differences among treatments. Averages used in this analysis were 9.6, 9.6, and 10.7 days to complete browsing for ammonium, urea, and nitrate nitrogen sources, respectively.

These results indicate that plantations of Douglas-fir seedlings would be equally susceptible to deer browsing regardless of the source of the N applied in the nursery. In the test, planting heights were carefully controlled since it has been recently shown that deer browse taller seedlings more readily than shorter ones among groups of similar-aged trees (Dimock 1971).

Chemical Properties

Since deer preference for treated seedlings was an important part of this study, concentrations of all chemical

constituents are expressed on a fresh-weight basis to allow comparison of levels as the animal encounters them in feeding. Trends in the results, however, do not change when the data are calculated on a dry-weight basis.

Chemical properties of seedling shoot tips (table 1) were affected less by nitrogen source than indicated by differences in growth between the seedlings (Radwan et al. 1971). Significant differences due to treatment were detected only in two properties. Manganese concentration was higher in the shoots of ammonium-fed seedlings than in shoots of the other

Table 1.--*Chemical properties of fresh foliage of Douglas-fir seedlings fertilized with different sources of nitrogen in the nursery*

Property	Unit of measure	Nitrogen treatment ^{1/}		
		Ammonium sulfate	Calcium nitrate	Urea
Moisture	percent	61.83 a	63.06 a	62.83 a
H-ion concentration	pH units	4.38 a	4.29 a	4.35 a
Titratable acidity	ml .1N-NaOH per 100 g	78.07 a	79.61 a	77.80 a
Total available carbohydrates	percent	6.12 a	5.78 a	5.87 a
Ash	percent	1.13 a	1.05 a	1.08 a
Total nitrogen	percent	.48 a	.47 a	.48 a
Soluble nitrogen	ppm	410 a	386 a	392 a
Calcium	ppm	2060 a	1980 a	2110 a
Potassium	ppm	1100 a	1333 a	1167 a
Sodium	ppm	20 a	16 a	17 a
Magnesium	ppm	610 a	540 a	560 a
Iron	ppm	38 a	34 a	35 a
Manganese	ppm	174 a	103 b	115 b
Phosphorus	ppm	790 a	730 a	764 a
Chlorine	ppm	112 a	91 a	93 a
Sulfur	ppm	284 a	191 c	224 b

^{1/} Fertilizers were applied to the seedlings in the nursery at 56 kg N/ha in May and again in September and seedlings were lifted in November. Values are averages of three composite samples, and means within each chemical property followed by the same letter do not differ significantly at the 5-percent level. To convert values of the last 13 components to dry-weight basis, multiply by 2.62, 2.71, and 2.69 for ammonium sulfate, calcium nitrate, and urea plants, respectively.

two treatments, and percentage sulfur was highest in the ammonium-cultured plants and lowest in those which received nitrate. However, because of smaller dry weights of shoots of ammonium plants (Radwan et al. 1971), absolute amounts of manganese and sulfur in the tops were approximately the same for all treatments.

Higher sulfur percentages in the ammonium and urea shoots may be due to increased uptake of sulfates added to the soil of these two treatments. Likewise, induced acidity in soil by ammonium sulfate probably increased availability of manganese to the ammonium plants. Resulting higher manganese content in shoots of these plants, however, was still within the range reported for needles of Douglas-fir nursery stock (Krueger 1967), and it is doubtful that it was sufficient to exert toxic effects.

Lack of differences among treatments in remaining chemical properties was unexpected. Differences in one or more of these properties due to N form have been shown earlier by other investi-

gators in Douglas-fir (van den Driessche 1971) and other conifers (Pharis et al. 1964, McFee and Stone 1968, Christersson 1972). However, concentration data are always subject to dilution by growth, and results based upon comparisons of concentrations vary with the magnitude of growth differences among treatments. Similar concentration data for most chemical components obtained here, therefore, resulted from the large difference in growth between the urea and nitrate plants and those from ammonium. The same difference, on the other hand, indicates that shoots of the urea and nitrate seedlings contained higher quantities of the majority of the chemicals determined, reflecting increased absorption and utilization of mineral nutrients by these plants compared with those from ammonium.

There was no evidence that plant shoots varied in pH or in total acidity due to treatment. Kirkby and Mengel (1967), however, noted differences in pH and in organic acid content in tomato plants due to the form of N supply in nutrient solution.

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KEYWORDS: Douglas-fir, *Pseudotsuga menziesii*, browse, deer, chemical analysis.

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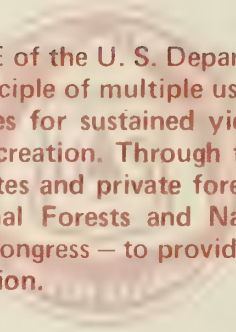
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Techniques for Evaluating *Bacillus thuringiensis* and Spray Equipment for Aerial Application against Forest Defoliating Insects

Bohdan Maksymiuk
and R.D. Orchard



PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

ABSTRACT

The most promising Dipel and Thuricide forestry spray formulations and spray equipment were studied to improve aerial application techniques and the effectiveness of *Bacillus thuringiensis* against forest insects. A fixed-wing aircraft, equipped with T8010 nozzles, was used to apply each formulation containing about 8 billion International Units of *Bacillus thuringiensis* per 2 gallons per acre to potted Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, trees. These trees were placed at 10-foot intervals across the spray swath and were subsequently bioassayed with test insects.

The spray formulations and spray equipment produced satisfactory drop-size spectra and spray deposit patterns. It was found that selected applications of *Bacillus thuringiensis* demonstrated high control potential for the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McD.), and western spruce budworm, *Choristoneura occidentalis* Freeman. The mean corrected larval mortality of the Douglas-fir tussock moth was 88 percent for the 100-foot and 78 percent for the 200-foot swath widths using Dipel. For the Thuricide treatment, the mean corrected larval mortality of the Douglas-fir tussock moth was 94 percent for the 100-foot and 87 percent for the 200-foot swath widths; the mean corrected larval mortality of the western spruce budworm was 100 percent for the 100-foot and 98 percent for the 200-foot swath widths. Higher deposits of *Bacillus thuringiensis* almost completely prevented insect defoliation to the test trees.

Keywords: *Bacillus thuringiensis*, Douglas-fir tussock moth, *Orgyia pseudotsugata*, western spruce budworm, *Choristoneura occidentalis*, pesticide application methods, spraying (- pest control).

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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife -- if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.



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U.S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

Bacillus thuringiensis (*B.t.*) provides a potential for controlling important forest defoliating insects such as the gypsy moth, *Porthetria dispar* (L.), in the northeastern United States (Lewis et al. 1974) and spruce budworm, *Choristoneura fumiferana* (Clements), in eastern Canada (Tripp 1972, Smirnoff et al. 1973). The U.S. Forest Service has recently become interested in the possible use of *B.t.* as a replacement for DDT against two major western defoliators, the Douglas-fir tussock moth, *Orgyia pseudotsugata* McDunnough, and the western spruce budworm, *Choristoneura occidentalis* Freeman. However, improved spray formulations, dispersal equipment, and aerial application methods are needed to increase the effectiveness and reproducibility of field treatments (Lewis and Connola 1966, Boving et al. 1971, Falcon 1971).

Based on the results of laboratory evaluation of the physical properties of 12 *B.t.* candidate forestry formulations^{1/} and on bioassay results with the larvae of the gypsy moth,^{2/} the two most promising formulations were selected for this investigation. This paper describes techniques and presents the results of the study conducted in 1972 to evaluate the performance of Dipel and Thuricide spray formulations and spray equipment^{3/} for increasing the effectiveness of aerial applications to control forest defoliating insects using the Douglas-fir tussock moth and the western spruce budworm as test insects.

^{1/} Bohdan Maksymiuk and John Neisess, unpublished data.

^{2/} Personal communication with N. R. Dubois, U.S. Forest Service, Northeastern Forest Experiment Station, Hamden, Conn. 06514.

^{3/} Mention of proprietary products in this paper does not constitute endorsement by the U.S. Department of Agriculture.

MATERIALS AND METHODS

CALIBRATION OF SPRAY EQUIPMENT

A Piper Pawnee airplane was equipped with three stainless steel spray tanks (10 gallons each) and a stainless steel boom. The system was pressurized by compressed air. TeeJet diaphragm nozzles with 8010 nozzle tips were used. The nozzles were positioned symmetrically on the left and right booms (fig. 1) and were pointed forward and down at 45 degrees to the thrust line of the aircraft. For determining swath deposit patterns and physical and biological swath widths, the spray equipment was calibrated to deliver 2 gallons per acre (gpa) at 80 miles per hour airspeed and a 100-foot swath width. Reduced flow rates were used for an accurate determination of spray atomization at 40 and 60 pounds per square inch. The reduced rates (about 0.5 gpa) were used for preventing overlapping of spray drops.

Flow rates were determined for water and for Dipel formulation. The intent was to use water for future calibration in the field. The flow rate was determined for the outermost and innermost nozzles. Water or formulation was collected for 1-minute intervals from the two nozzles. The amount of water or the Dipel formulation collected was measured with a graduated cylinder. Three replicate calibrations were made with the water, and two with Dipel. A hand sprayer with an 8010 spray nozzle was used to determine calibrations for the Thuricide formulation.

FORMULATIONS

The most promising Dipel, Lot No. 3980-167A, and Thuricide, Lot No. 11164, experimental forestry formulations were selected for these tests (see footnote 1).

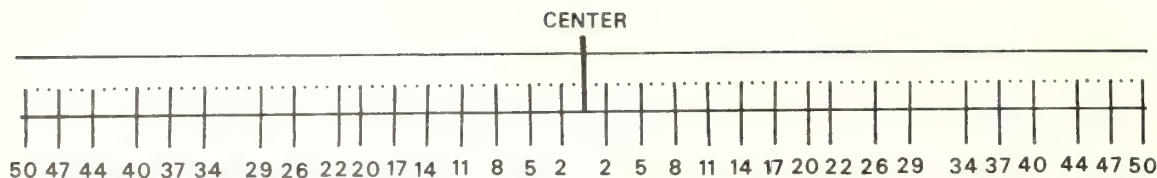


Figure 1.--Arrangement of T8010 nozzles along spray boom for testing Dipel and Thuricide formulations. This arrangement of 32 nozzles was used for determining swath deposit patterns for application rate of 2 gal/acre at 40 psi. 26 nozzles, numbered 2, 5, 8, 11, 14, 17, 20, 22, 26, 29, 34, 37, and 40, were used for determining swath deposit patterns for application rate of 2 gal/acre at 60 psi. 8 nozzles, numbered 8, 17, 26, and 34, were used for determining spray atomization at 40 and 60 psi.

The Dipel formulation contained: Dipel (Abbott Laboratories, North Chicago, Ill.), a wettable powder--227 grams; Cargill Insecticide Base (Cargill, Inc., Minneapolis, Minn.)--1 quart; propionic acid (Monsanto Co., St. Louis, Mo.)--7.57 milliliters; Santoquin (Monsanto Co., St. Louis, Mo.)--0.76 milliliter of 0.02 percent; Maywood formula (Maywood Chemical Co., Maywood, N. J.)--120 milliliters; and water--to make 1 gallon. The Thuricide formulation contained: Thuricide HPC (IMC Corp., Libertyville, Ill.), an emulsifiable concentrate--1 quart; Cargill Insecticide Base--1 quart; Chevron Spray Sticker (Chevron Chemical Co., San Francisco, Calif.)--4 fluid ounces; and water--to make 1 gallon.

The spray formulations contained a fluorescent tracer for deposit assessment (0.1 percent weight per volume Brilliant Sulphoflavine FFA, General Aniline and Film Corp., New York, N. Y.). Dipel contained 7.26 and Thuricide 8 billion International Units (IU) of potency per 2 gallons of finished spray to be applied per acre.

TEST ORGANISMS

Third- and fourth-instar larvae of the Douglas-fir tussock moth were used

as test insects to determine the biological swath width for the Dipel formulations. Third- and fourth-instar larvae of the Douglas-fir tussock moth and the western spruce budworm were used for bioassay to determine the biological swath width for the Thuricide formulation.

Potted, greenhouse-grown Douglas-fir trees, *Pseudotsuga menziesii* (Mirb.) Franco (about 18 inches high), with the new flush of foliage, were used in all tests, including controls. Bioassay was used to determine biological swath width and patterns of larval mortality across the spray swath.

TEST CONDITIONS

Tests with the Dipel and Thuricide formulations were conducted at the 50-acre, open-ground airport test site where a rotating platform for sampling aerial sprays was installed (fig. 2). Meteorological conditions and application variables are shown in table 1. During the spray tests, wind speeds did not exceed 4 miles per hour. The following standardized procedure was used:

1. One potted tree, one white Kromekote card (4x5 inches), and two aluminum plates (6x6 inches) per each of 51 sampling stations were placed in line



Figure 2.--Rotating platform for sampling aerial sprays.

Table 1.--Test parameters and meteorological conditions

<i>Exallus</i> <i>thuringiensis</i> and flight number ^{1/}	Number of nozzles, T8010	Gallons per acre	Spray pressure (lb/in ²)	Time (a.m.)	Temperature, °F		Wind		Platform orientation
					2 ft	4 ft	Mi/h	Direction	
Dipel:									
1	8	0.5	40	5:56	44	44	1.0	S	E to W
2	8	.5	60	6:25	44	44	1.5	SE	E to W
3	26	2.0	60	7:08	46	46	2.0	SE	E to W
4	32	2.0	40	7:55	48	47	4.0	S	N to S
Thuricide:									
1	8	.5	40	6:15	40	41	2.0	W	N to S
2	8	.5	58	6:40	46	45	1.0	SW	N to S
3	26	2.0	62	7:34	52	51	.5	W	N to S
4	32	2.0	40	8:30	58	56	1.0	SW	N to S

^{1/} 50-foot spraying height.

at 10-foot intervals on the rotating platform.

2. The platform was rotated to obtain either upwind or crosswind test flights as needed.

3. Each *B. t.* formulation was applied by an airplane flying at right angles to the platform; the indicated air speed was 80 miles per hour; and the spraying height was about 50 feet above the sampling platform. The spray was turned on 500 feet before the platform was reached and turned off 500 feet after it was passed.

4. A waiting period of 15-20 minutes allowed the spray to reach the surfaces of the samples (trees, cards, plates). A perforated plastic bag was then slipped over each potted tree before transport to the laboratory for bioassay.

5. Likewise, the Kromekote cards and aluminum plates were removed from each sampling station on the platform, placed in slotted boxes, and transported to the laboratory for spray deposit assessment.

BIOASSAY

In the laboratory, incisions were made in the plastic bags; 10 larvae were

placed on the foliage of each of the field-labeled, potted trees; and the incisions were sealed with masking tape. In a similar manner, controls (10 larvae per each of 10 potted trees) had been set up before treatments to avoid possible contamination of foliage with *B. t.* All trees were kept at a temperature of about 22° C and watered to sustain the quality of foliage for larval feeding.

All treated and control plants were examined daily; and where the foliage had been depleted almost entirely, the larvae were transferred to untreated, potted trees. Six days after the treatment all living larvae were transferred to new untreated, potted trees, the dead larvae were removed from the plastic bags, and the mortality was recorded. Thirteen days after the treatment, the mortality was again determined and the remaining living larvae were transferred to artificial media in petri dishes for additional observation.

Frass produced by the larvae of the Douglas-fir tussock moth and spruce budworm was collected during the examination of larval mortalities in the

Thuricide treatment. Frass was oven-dried at 70° C for 24 hours and weighed.

SWATH WIDTH

Biological and physical swath widths for Dipel and Thuricide formulations were determined by plotting the percent of larval mortality together with the quantity of spray deposit across the spray swaths. Biologically effective swath widths and the pattern of larval mortality were determined only for finer spray atomization produced by a spray pressure of 60 pounds per square inch. Physical swath widths were also determined for the coarser spray atomization produced by a spray pressure of 40 pounds per square inch.

Spray deposit was expressed in terms of gallons per acre and the mean number of spray drops per square centimeter across the spray swaths. Physical swath widths and spray deposit distribution patterns were determined by fluorometric analysis of deposit (Yates and Akesson 1963) taken from two aluminum plates per each sampling station. The spray deposit was removed from each plate by washing with 10 milliliters of distilled water. The concentration of fluorescent tracer was determined by a Turner Model 430 Spectrofluorometer. The quantity of spray deposit, in gallons per acre, was determined by relating the

amount of the fluorescent tracer to gallons per acre based on previously determined standard curves. The number of spray drops was determined from deposit appearing on a 4-square-centimeter central area of each Kromekote card.

SPRAY ATOMIZATION

Spray atomization, expressed as the volume median diameter (vmd),^{4/} was determined from the deposit on the white Kromekote cards by using previously developed methods (Maksymiuk and Moore 1962, Maksymiuk 1964).

RESULTS AND DISCUSSION

DIPEL SPRAY FORMULATION

Calibration of spray equipment.--

The calibration of the aircraft spray system is summarized in table 2. The flow rates of the finished Dipel formulation, tested at spray pressures of 40 and 60 pounds per square inch, were found to be essentially the same as for water. Therefore, water can be used for future calibrations of similar formulations. The

^{4/} Volume median diameter (vmd) is the diameter of a drop which satisfies the requirement that half the volume of liquid be in drops smaller, and half in drops larger, than itself.

Table 2.--Calibration of spray equipment (T8010 nozzles)

Pressure (lb/in ²)	Flow rate of H ₂ O		Flow rate of Dipel	
	Center nozzle	Outer nozzle	Center nozzle	Outer nozzle
----- gallons per minute -----				
40	1.0010	0.9773	1.0270	0.9993
60	1.2349	1.2085	1.2305	1.2007

flow rates of the 8010 spray nozzles showed no practical variation regardless of their position on the spray boom. The uniform spray pressure should result in delivery of an accurate amount of spray. The flow rates of water and Dipel increased consistently with the increased spray pressure.

Evaluation of formulation.-- Two problems were encountered with the Dipel formulation. First, presence of cane fibers in the molasses formulation as it was received from the manufacturer might have plugged the nozzles of the spray equipment. This problem was remedied by filtering the formulation through a 50-mesh filter and by removing all the screens and filters in the spray equipment. It was very important to remove the screens and filters of the spray equipment; otherwise reduced flow rates could result. Second, the Dipel formulation tended to foam when vigorously agitated or pumped at high pressure

into a spray tank. Foaming could be greatly reduced by pumping at a lower pressure, by using a hose that would not constrict the flow, or by stirring the foamy formulation.

Spray atomization.-- Spray atomization data (vmd) are summarized in table 3. Increasing the spray pressure from 40 to 60 pounds per square inch resulted in the decreased vmd from 321 to 266 microns. The finer spray atomization produced more spray drops which can result in a higher density of deposit coverage, assuming no excessive evaporation and/or drift.

Biological and physical swaths.-- Larval mortality for 100-foot and 200-foot swath widths are presented in table 3. The relationships between the larval mortalities (13 days) of the Douglas-fir tussock moth and the spray deposit in gallons per acre are shown graphically (fig. 3). These bioassay data show that the selected

Table 3.--*Summary of insect mortality and spray atomization data for Dipel and Thuricide formulations*

Formulation and test insect	Larval mortality for swath width ^{1/}		Vmd	
	100 feet ² (60 lb/in ²)	200 feet ² (60 lb/in ²)	40 lb/in ²	60 lb/in ²
	- - - - Percent - - - -		- - - - Microns - - - -	
Dipel:				
Douglas-fir tussock moth	88	78	321 ± 11 ^{2/}	266 ± 25
Thuricide:				
Douglas-fir tussock moth	94	87	231 ± 37	199 ± 8
Western spruce budworm	100	98	231 ± 37	199 ± 8

^{1/} Mortality data are corrected for controls using Abbott's formula (13 days).

^{2/} Standard error of the mean of 3 determinations.

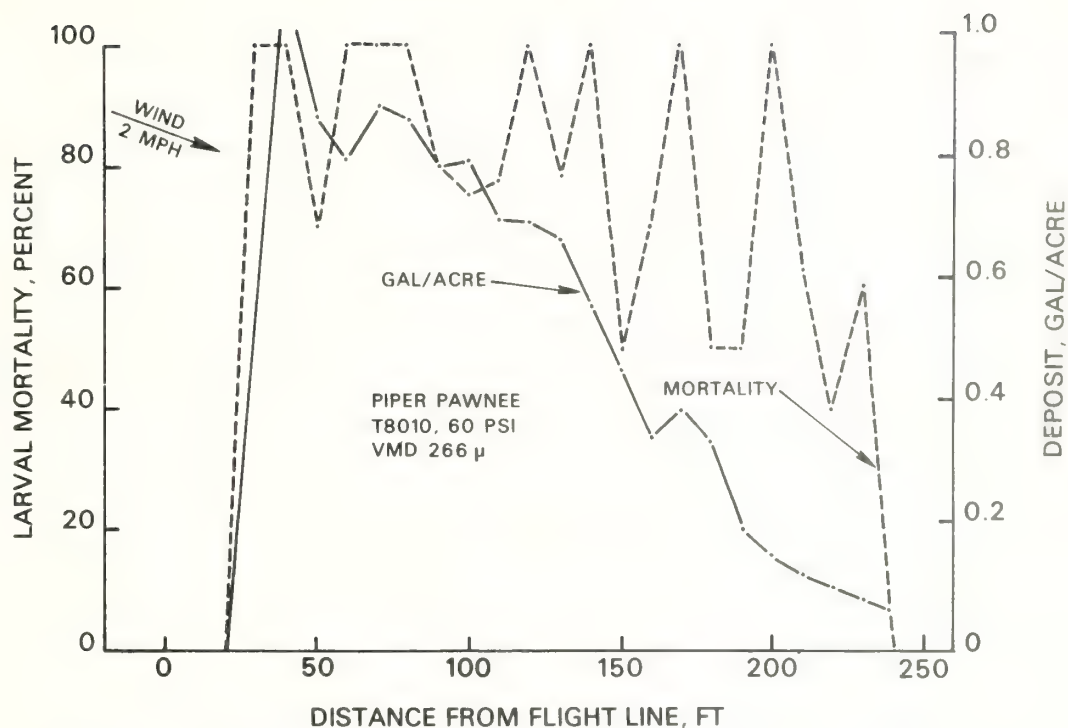


Figure 3.--Relationship between Douglas-fir tussock moth mortality and spray deposit in gallons per acre for Dipel.

spray equipment and Dipel formulation produce wide, biologically effective swaths.

The relationship between spray deposit in gpa and number of drops per square centimeter for the vmd of 266 microns (spray pressure of 60 pounds per square inch) is presented in figure 4. Similarly, the relationship between spray deposit in gpa and number of drops per square centimeter for the vmd of 321 microns (spray pressure of 40 pounds per square inch) is shown in figure 5. By comparing the swath widths (figs. 3 and 4 with fig. 5), it is evident that the finer atomization resulted in a wider swath width. This was despite the fact that there was less crosswind (2 miles per hour) for using spray atomization containing a vmd of 266 microns as compared to more crosswind (4 miles per

hour) for using spray atomization having a vmd of 321 microns.

THURICIDE SPRAY FORMULATION

Calibration of spray equipment.--

It was found that the flow rates of spray formulation from the hand sprayer closely approximated the aircraft calibrations when the same nozzles and operating spray pressures were employed. Therefore, calibrations for Thuricide spray formulations were made with a hand sprayer equipped with an 8010 nozzle at spray pressures of 40 and 60 pounds per square inch. The flow rates at 40 and 60 pounds per square inch were 0.9374 and 1.340 gallons per minute, respectively.

*Evaluation of formulation.--*No problems were encountered in the flowability of the Thuricide spray formulation

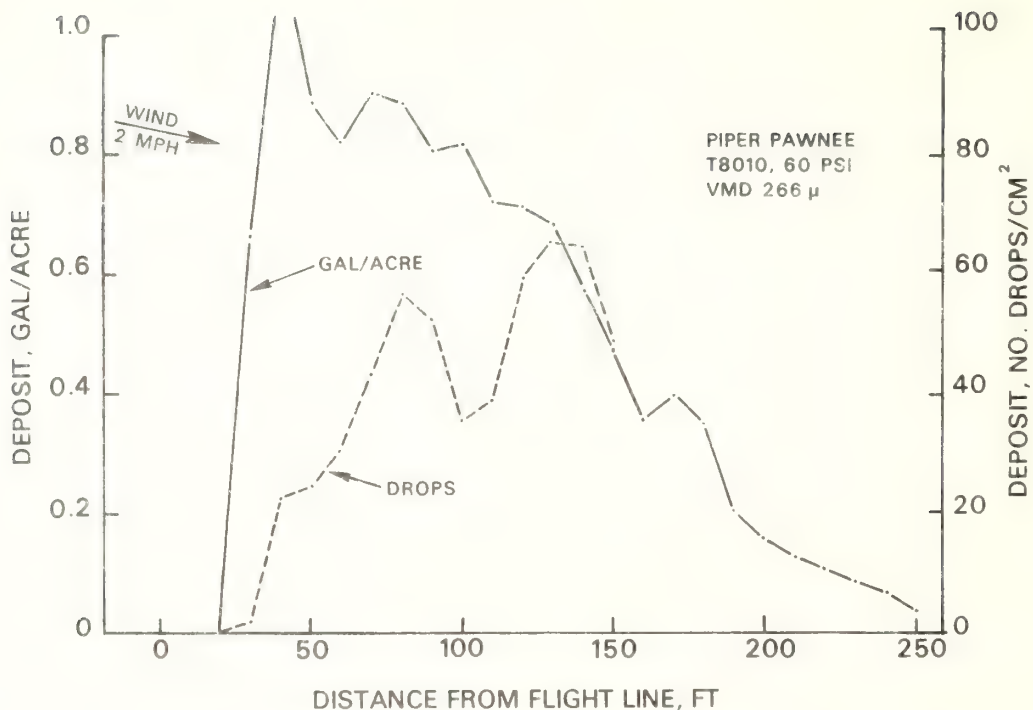


Figure 4.--Relationship between spray deposit expressed in gallons per acre and number of spray drops per square centimeter for Dipel; vmd of 266 microns.

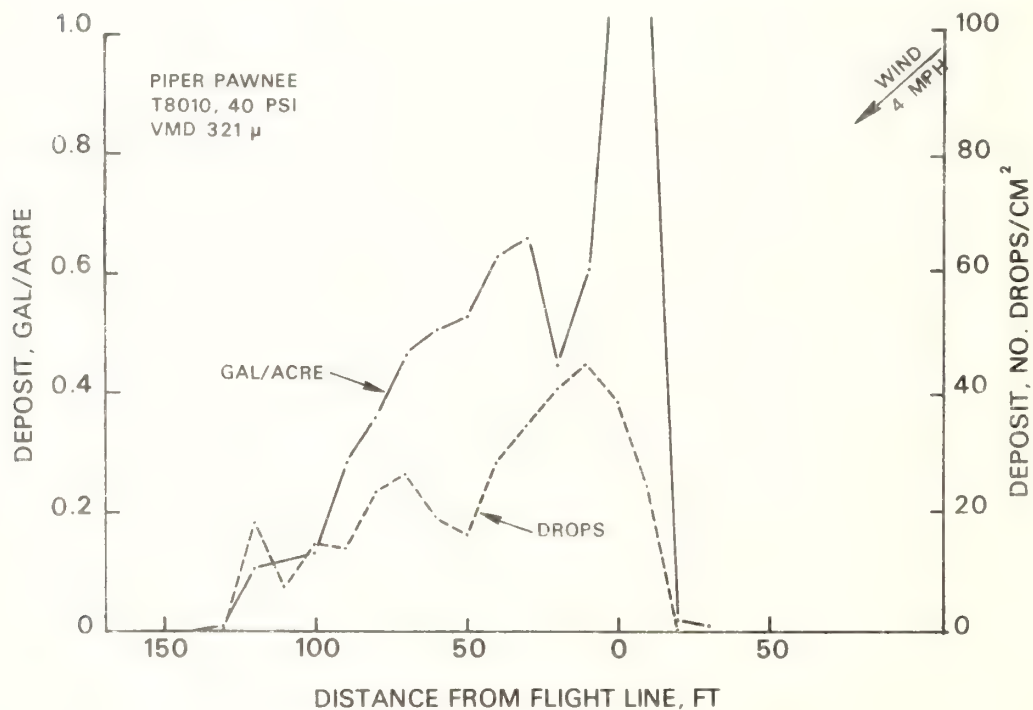


Figure 5.--Relationship between spray deposit expressed in gallons per acre and number of spray drops per square centimeter for Dipel; vmd of 321 microns.

through the spray equipment. Before being loaded into the aircraft, the formulation was filtered through a 50-mesh wire filter. No excessive amount of sediment was then found. Similarly, as with the Dipel formulation, all screens and filters were removed from the spray equipment to prevent possible plugging and irregular flow rates.

Spray atomization.--The spray atomization data for Thuricide are given in table 3 together with the Dipel formulation for convenient comparisons. Increasing the spray pressure from 40 to 60 pounds per square inch resulted in decreased vmd from 231 to 199 microns.

Biological and physical swaths.--Larval mortalities for 100-foot and 200-foot swath widths are given in table 3. The relationship between larval mortality (13 days) of the Douglas-fir tussock moth and spray deposit (gallons per acre) patterns across the spray swath is shown in figure 6. Comparable data for the distribution of mortality across the spray swath of the western spruce budworm are given in figure 7. These bioassay data show that the selected spray equipment and Thuricide *B.t.* spray formulation produced wide biologically effective swaths for the two test insects. It was found that the Thuricide formulation was more effective against the larvae of the western spruce budworm than against the larvae of the Douglas-fir tussock moth (figs. 6 and 7 and table 3).

The relationship between spray deposit in gallons per acre and number of spray drops per square centimeter for the vmd of 199 microns, across the spray swath, is illustrated in figure 8. The same relationship for vmd of 231 microns is depicted in figure 9. These graphs indicate satisfactory swath patterns in both the quantity and the density of spray deposits. However, finer atomization resulted in a higher drop density.

The relationships between larval mortality and larval frass of the Douglas-fir tussock moth and the western spruce budworm are depicted in figures 10 and 11, respectively. It was found that there was high negative correlation between insect mortality and frass production. There was virtually no larval feeding, as indicated by frass, on trees with high spray deposits (figs. 6 and 10 for the Douglas-fir tussock moth and figs. 7 and 11 for the western spruce budworm).

In conclusion, the reported techniques will be helpful in evaluating the performance of spray formulations and equipment for more effective aerial applications of microbial insecticides. The selected Dipel and Thuricide *B.t.* formulations and spray equipment performed satisfactorily. A 100-foot swath width is recommended for field use for a small, fixed-wing aircraft equipped with a conventional spray boom and nozzles. Results indicate that *B.t.* has a high potential for control of the Douglas-fir tussock moth and the western spruce budworm.

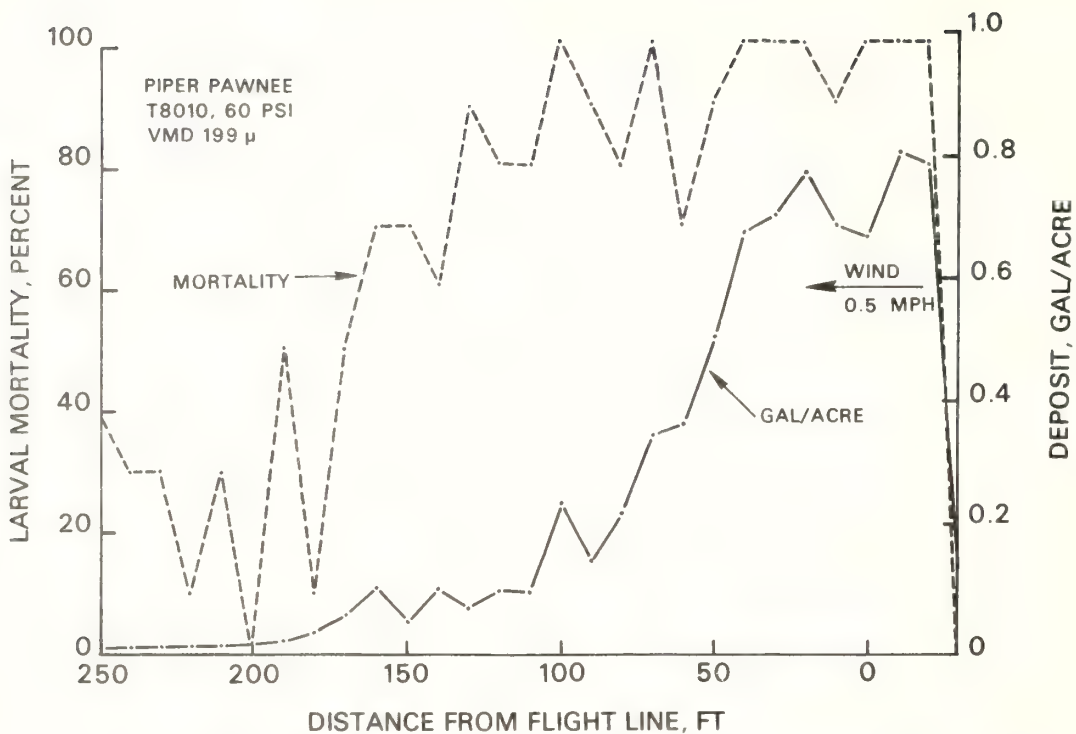


Figure 6.--Relationship between Douglas-fir tussock moth mortality and spray deposit in gallons per acre for Thuricide.

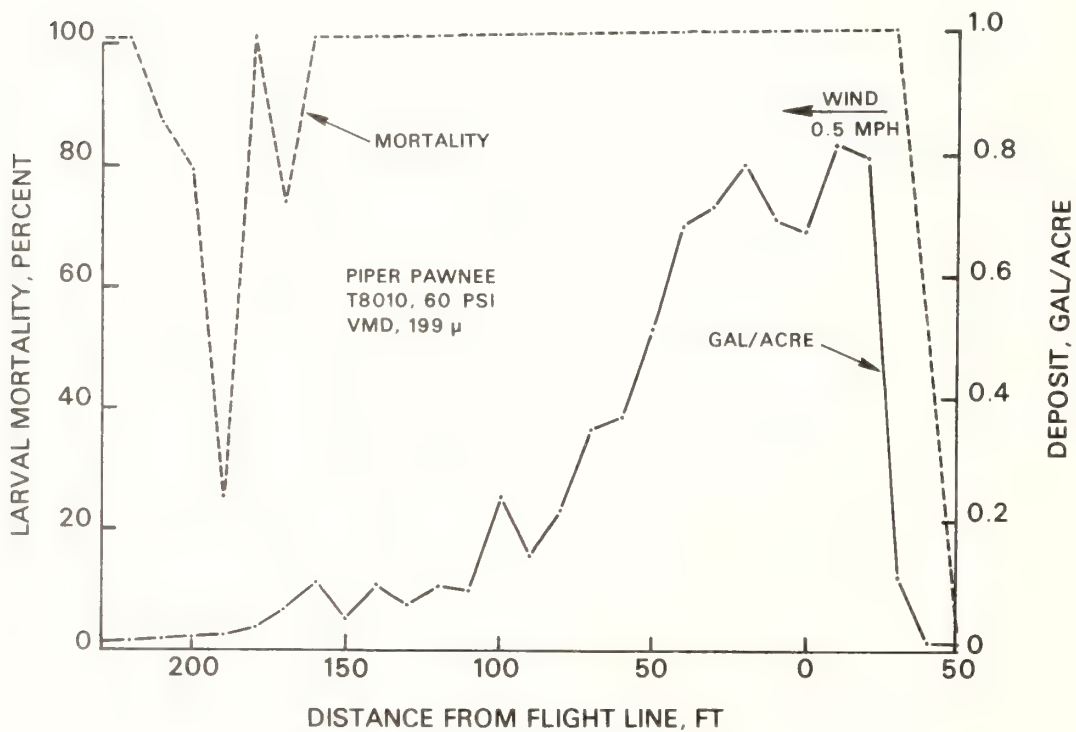


Figure 7.--Relationship between spruce budworm mortality and spray deposit in gallons per acre for Thuricide.

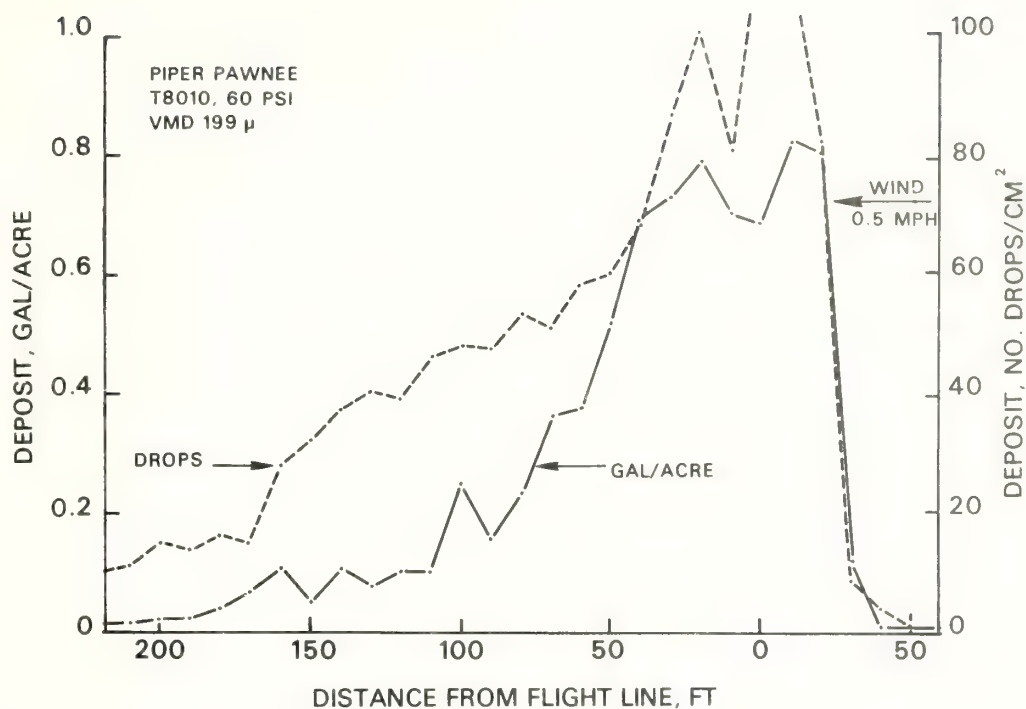


Figure 8.--Relationship between spray deposit expressed in gallons per acre and number of drops per square centimeter for Thuricide applied at 60 pounds per square inch.

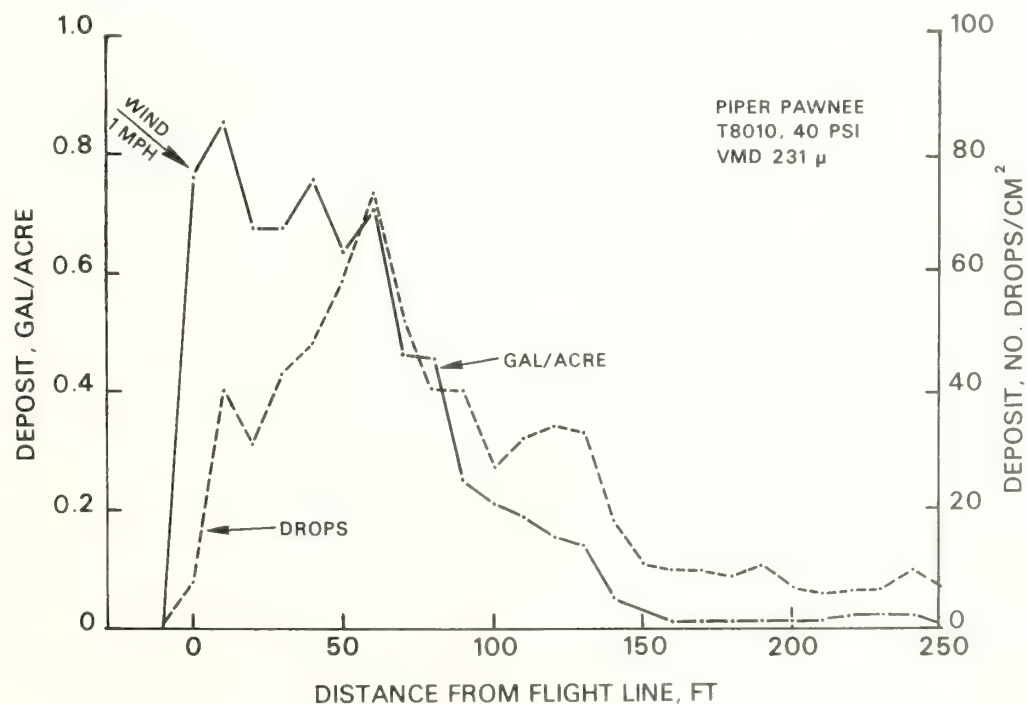


Figure 9.--Relationship between spray deposit expressed in gallons per acre and number of spray drops per square centimeter for Thuricide applied at 40 pounds per square inch.

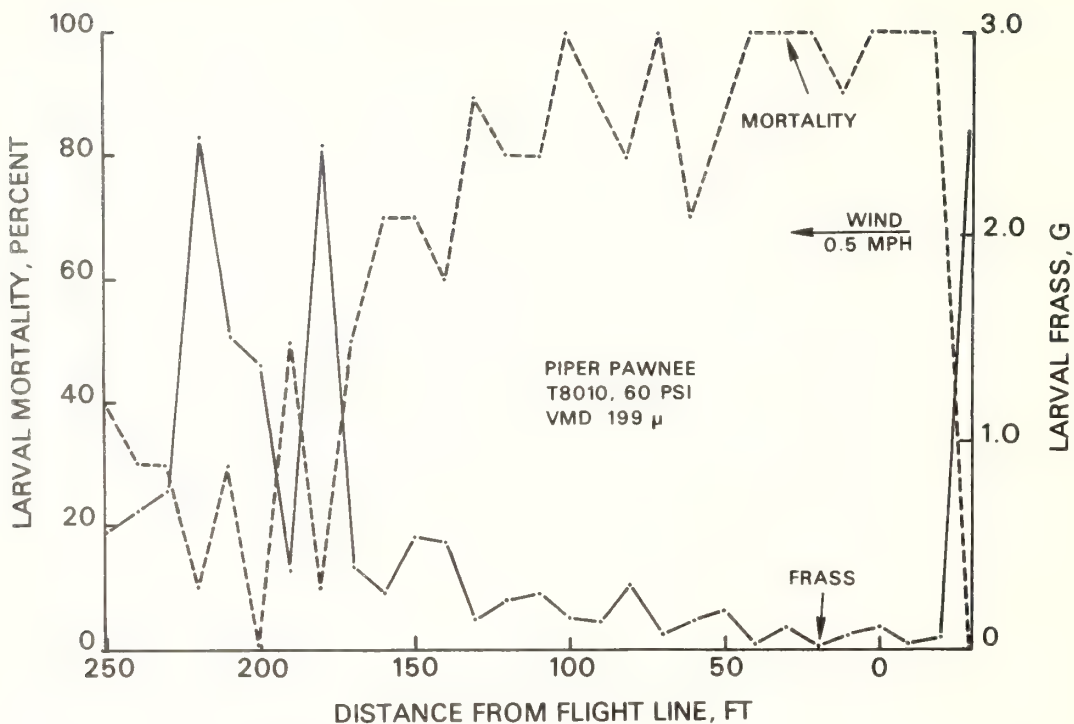


Figure 10.--Relationship between Douglas-fir tussock moth mortality and oven-dried frass (13 days) for Thuricide.

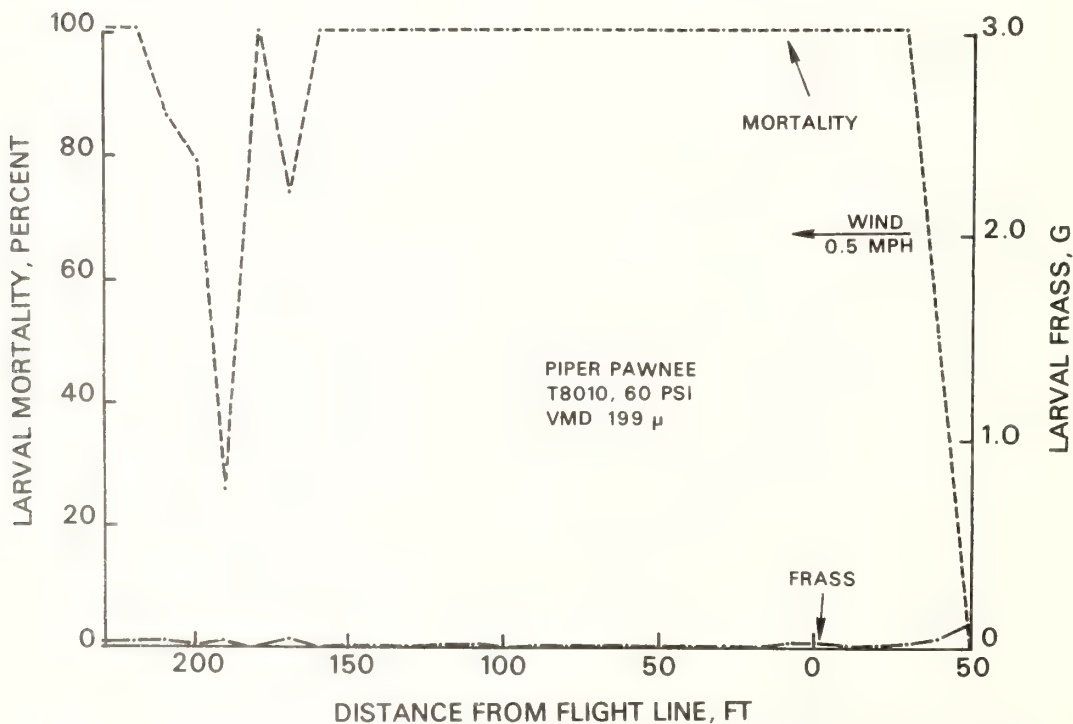


Figure 11.--Relationship between western spruce budworm mortality and oven-dried frass (13 days) for Thuricide.

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1974. Techniques for evaluating *Bacillus thuringiensis* and spray equipment for aerial application against forest defoliating insects. USDA For. Serv. Res. Pap. PNW-183, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Suitable aircraft application techniques were developed for Dipel and Thuricide applications. Resulting sprays showed potential for controlling the Douglas-fir tussock moth, *Orgyia pseudotsugata*, and western spruce budworm, *Choristoneura occidentalis*.

Keywords: *Bacillus thuringiensis*, Douglas-fir tussock moth, *Orgyia pseudotsugata*, western spruce budworm, *Choristoneura occidentalis*, pesticide application methods, spraying (- pest control).

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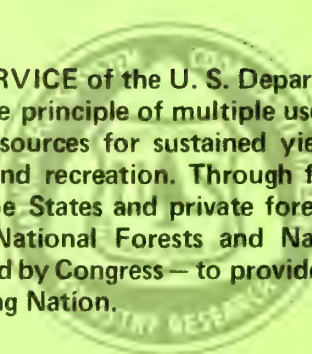
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SPATIAL DISTRIBUTION OF LUMBER DEGRADE IN WHITE FIR TREES



W. Y. PONG
W. WAYNE WILCOX

ABSTRACT

The spatial distribution of lumber degrade was determined and analyzed in 20 white fir trees. A general pattern of increasing degrade from pith to bark in the radial direction was observed. In the vertical direction, degrade initially decreased and then increased with height.

Results suggest that both the grade of the lumber from a given location in the tree and the uniformity of that lumber with respect to the drying sort material (sinker, sap, or corky) can affect the magnitude and pattern of degrade in white fir.

This study suggests that decreased degrade might result if additional drying sorts were made in the current sap and sinker sort. This study also indicates that wetwood, by itself, previously considered to be a source of lumber drying problems, has little or no effect on degrade.

KEYWORDS: Lumber recovery studies, white fir, lumber grading, seasoning.

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INTRODUCTION

Lumber degrade has been the subject of numerous investigations concentrated mainly in the phenomenon of processing logs to lumber, with little attention being given to degrade relative to the tree.

Research in the drying of white fir has touched on the degrade-tree relation when it recognized the need for sorting white fir lumber prior to drying (Smith and Dittman 1960a, 1960b). In these studies the primary emphasis was on the drying process, particularly with relation to moisture content and drying time. Recent investigations on wood of white fir (Wilcox 1968, Wilcox and Pong 1971) have shown the properties of the wetwood portion to be comparable to those found elsewhere in the tree. The slower drying rate associated with wetwood has been attributed in part to the higher density and lower diffusion coefficient of this wood (Arganbright and Wilcox 1969).

The effects of certain pathological defects on lumber grade yield and lumber degrade have also been studied. Differences in recovery of certain grades of white fir lumber were found to be associated with logs infected with dwarf mistletoe; there were, however, no apparent effects of this defect on lumber degrade (Wilcox et al. 1973). In red oak, bacterial-infected wood was found to be more susceptible than noninfected wood to honeycomb and ring failure (Ward et al. 1972), both of which are lumber degrading factors.

Results from the foregoing studies suggest that many of the degrade problems associated with lumber drying have their origin in the raw material and not in processing. Identifying in the trees the troublesome locations producing lumber potentially high in degrade would allow processors greater flexibility in coping with the problem.

In white fir, in particular, the problem of lumber degrade appears to be closely associated with location in the tree; however, data to substantiate this or to indicate these locations had never been collected. In conjunction with a larger study (Pong 1971, Wilcox and Pong 1971) on wood properties and lumber quality in white fir, it was possible to collect data on the degrade of white fir lumber relative to its location in the tree. This paper reports the results of that portion of the study dealing with the distribution of lumber degrade in white fir trees.

MATERIALS AND METHODS

Twenty white fir (*Abies concolor* (Gord. and Glend.) Lindl.) trees, representative of the range of diameters and heights of trees commonly logged in the area (see table 1), were selected for the study from a single stand of mixed conifers in El Dorado County, California. The selection area was located on the west side of the Sierra Nevada at an elevation of 6,200 feet. The relatively young stand on a good site was predominately a white fir/incense-cedar/sugar pine timber type.

Surface characteristics of each tree to be logged were diagramed (Jackson et al. 1963, Pong and Jackson 1971), and other important details of the tree and surrounding area were noted and recorded. The identity of each tree was maintained throughout the study with an assigned number. After felling and bucking, tags containing the identifying tree and log numbers were stapled on the ends of each log so that the log's position in the standing tree would remain known throughout processing. A net scale of 50 percent or more of gross scale was required of all study logs. Logs were graded by using a system of three grades (Wise and May 1958): Select (grade 1), Shop (grade 2),

Table 1.--*Distribution of size and age of white fir study trees*

Tree number	D.b.h.	Total height	Age ^{1/}
	<i>Inches</i>	<i>Feet</i>	<i>Years</i>
1	24.3	100	143
2	23.8	97	95
3	46.2	142	141
4	46.4	182	150
5	18.6	99	145
6	21.2	110	145
7	21.5	104	83
8	17.2	94	79
9	28.0	137	147
10	29.8	139	139
11	37.4	158	144
12	38.1	160	143
13	24.9	115	98
14	20.7	92	94
15	20.1	88	130
16	32.4	156	149
17	46.9	175	169
18	39.2	165	176
19	40.7	168	146
20	37.1	129	109

^{1/} At stump height.

and Common (grade 3).^{1/} Log lengths taken varied from 10 to 20 feet (table 2) and diameters, from 10 to 39 inches (table 3).

Prior to sawing, the large end of each log was painted in a target pattern with three colors; each band of color covered approximately one-third of the log radius. The paint color on the ends of the resulting boards delineated, to the nearest third of the radius, the radial position within the log from which the board had come.

^{1/} Logs in the Common grade include both high and low Commons.

Table 2.--*Distribution of study logs by length and log grade*

Log length (feet)	Log grade ^{1/}			
	1	2	3 ^{2/}	All grades
- - - - - Number - - - - -				
10	0	0	10	10
12	0	0	9	9
14	0	1	3	4
16	8	11	67	86
18	0	0	2	2
20	0	0	1	1
Total	8	12	92	112

^{1/} See Wise and May (1958).

^{2/} Logs in this grade include high and low Commons.

Table 3.--*Distribution of study logs by diameter class and log grade*

Diameter inside bark (inches)	Log grade ^{1/}			
	1	2	3 ^{2/}	All grades
- - - - - Number - - - - -				
9.6 - 12.5	0	0	15	15
12.6 - 15.5	0	3	15	18
15.6 - 18.5	0	3	15	18
18.6 - 21.5	0	0	9	9
21.6 - 24.5	1	1	15	17
24.6 - 27.5	1	1	11	13
27.6 - 30.5	3	2	4	9
30.6 - 33.5	2	0	4	6
33.6 - 36.5	0	2	4	6
36.6 - 39.5	1	0	0	1
Total	8	12	92	112

^{1/} See Wise and May (1958).

^{2/} Logs in this grade include high and low Commons.

Each log was sawn with the intent of recovering the optimum value through manufacture of usual lumber items. Sawing practice during the study period conformed to general industry practice in the west-side Sierra and was geared to produce Select, Shop, Common, and Dimension lumber. All lumber was sawn to meet Western Wood Products Association specifications. All material cut from a given log was color-coded at the headsaw as the log was initially broken down. From this code, crewmembers numerically identified each board with the appropriate number of the log from which the board was sawn. On the green chain each board was stamped consecutively with a number, marked for drying sort by mill personnel, and then graded by a certified grader. Trimming of lumber at all stages in the study was by pencil only; actual trimming of the study lumber was not done until after it was surfaced and graded.

It was the practice of the mill where the study was performed to segregate the green lumber into three drying sorts (sap, corky, and sinker) (Smith and Dittman 1960a) for each of four thicknesses (4/4, 5/4, 6/4, and 7/4). A fourth sort (4- by 4-inch Dimension) called "No. 4" or dunnage was cut from the shaky cores. Normally there is no green grading of the white fir lumber by the mill. Study lumber was not tallied in the green condition except for the No. 4 and all of the 4/4 lumber; these were hand-tallied by board number, mill log number, green grade, width, length, and thickness. Since there was to be no further processing of the dunnage and the 4/4 lumber, we assumed the green grade of this lumber would have held true if dried and surfaced. The remainder of the lumber was tallied after kiln drying.

Modern, single track, internal fan, cross-circulation kilns were used to dry

the study lumber. For each of the three basic drying sorts, a different kiln charge and schedule were used (table 4). Each schedule gives a 5- to 10-percent redry and an average moisture content of 15 to 16 percent, with a maximum moisture content of 19 percent.

After drying, the lumber was sorted for surfacing on the dry sort chain. During dry sorting, a photographic record of each board was made on color film using a cinepulse camera triggered by an automatic photo-electric pulser (Pong et al. 1970). The film record for each board contained the end color code, sequential board number, log number, drying sort, green and rough-dry grades, pencil trim, defects and other surface conditions, width, length, and thickness (fig. 1). Each board was also tallied by hand to show green and dry grades, any pencil trimming, board and log numbers, length, width, and thickness.

Rough-dry Dimension lumber was surfaced on four sides and Selects and Shops, on two sides. Boards entering the planer were recorded on data sheets by the numbers originally stamped on the green chain. As each board left the planer, it was graded, pencil trimmed, and a consecutive number written on its surface. This number coincided with the number of entries made on the data sheets on the infeed side of the planer. Each surfaced board was then photo-recorded on color film.

DATA PROCESSING AND ANALYSES

Hand-tallied data for rough-green and rough-dry boards were edited and corrected using the photographic record made on the dry sort chain. The tally of consecutive numbers made at the infeed side of the planer was matched and

Table 4.--Dry kiln schedules for sap, sinker, and corky white fir
lumber, American Forest Products Corporation,
Martell, California

Timespan (hours)	Temperatures		
	Dry bulb	Wet bulb	Wet bulb depression

- - - - - Degrees F - - - - -

Sap:

0-36	160	140	20
37-76	170	140	30
77-100	180	140	40
101-106 conditioning	--	--	--
Total time: 106 hours	--	--	--

Sinker:

0-24	160	140	20
25-60	170	140	30
61-168	180	140	40
169-174 conditioning	--	--	--
Total time: 174 hours	--	--	--

Corky:

0-24	160	140	20
25-54	170	140	30
55-60 conditioning	--	--	--
Total time: 60 hours	--	--	--

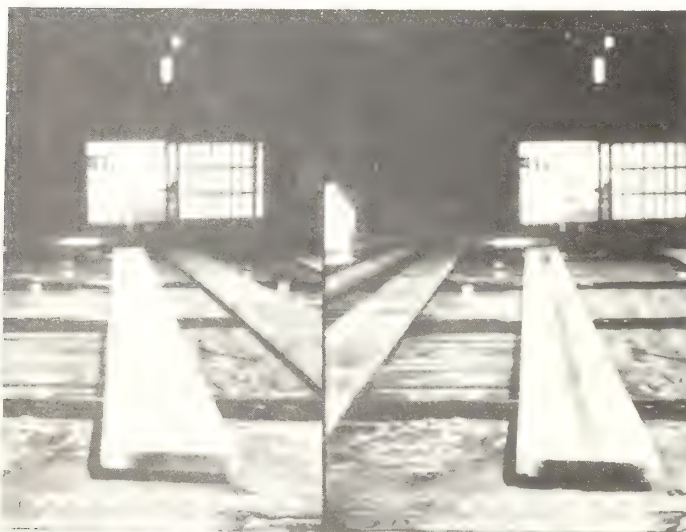


Figure 1.--Consecutive frames
from the photographic record
made on the dry sort chain
during sorting of white fir
study lumber.

corrected with the rough-green and rough-dry board tallies. The board data for the surfaced lumber were then transferred from the film record of the surfaced lumber to the data sheets containing the consecutive board numbers.

The radial location of each study board in the log was determined by visually rating to the nearest 10 percent the percentage of its end area occupied by each of the radial position color codes. To insure accuracy, two independent ratings were made on all boards.

Data for each phase of the study were transferred from tally sheets to punched cards. A detailed matching of the card data was then made for each board in rough-green, rough-dry, and surfaced-dry condition. Board cards were segregated prior to processing into four radial groups of end color codes: center, middle, outer, and mixed. Boards

with end codes of two colors were placed in the first three radial groups (see table 5). Boards with codes of three colors were placed in the fourth group, since the radial origin of these boards was not readily discernible. The cards were analyzed by automatic data processing for grade and volume change after each stage of processing (Pong 1971) for various combinations of log position, radial segregation, log grade, and drying sort. Common grades of lumber, i.e., 2, 3, and 4 Common, were combined with the Dimension grades of Standard, Utility, and Economy, respectively.

The percent of lumber that degraded--i.e., downgraded one or more grades after each processing stage and segregated by radial location and vertical position in the tree--was analyzed by analysis of variance and covariance. Log diameter and percent log defect were selected as covariates in the analyses.

Table 5.--Board end color code combinations included in each radial segregation of study lumber

Board end color ^{1/}	Radial segregations																	
	Center							Middle							Outer			
	----- <i>Percent</i> -----																	
Black	100	90	80	70	60	50	40	30	20	10								
Yellow		10	20	30	40	50	60	70	80	90	100	90	80	70	60	50	40	30
Green													10	20	30	40	50	60
																	70	80
																		100

^{1/} Colors are listed with increasing distance from pith.

RESULTS

The 112 logs included in this study produced over 43,000 board feet of lumber. The volume of lumber in each of the radial segregations for each stage in processing is presented in table 6. Differences in volume in a given radial segregation represent, in the main, pencil trim "losses" following each processing stage. Boards coded with three colors (the "mixed" segregation) totaled less than 10 percent of the study material.

Table 7 shows the percent degrade occurring in each of four radial segregations of lumber from four log positions after various stages of processing. The radial distribution of degrade for each of four log positions after each processing step is presented in figure 2, and the vertical distribution of degrade for each

radial segregation is presented in figure 3. In general, these distributions suggest that degrade increases with distance from the pith at all log positions; for each radial segregation of lumber, degrade initially decreases with height and then increases.

Statistical analysis of the data summarized in table 7 showed that degrade among segregated groups of lumber in the radial direction differed significantly at the 5-percent level in only log positions 1 and 2 when going from the rough-dry to surfaced-dry condition. Vertically, degrade of lumber from different logs in the tree was significantly different at the 5-percent level in only the center radial segregation of lumber when going from the rough-dry to surfaced-dry condition. In these analyses, the "mixed" segregation was not included because of the indeterminate radial origin of the data.

Table 6.--*Radially segregated volumes of study lumber in rough-green, rough-dry, and surfaced-dry condition*

Radial segregation	Lumber condition		
	Rough-green	Rough-dry	Surfaced-dry
- - - - - Board feet - - - - -			
Center	11,763	11,720	11,622
Middle	10,080	10,038	9,899
Outer	17,089	16,990	16,559
Mixed	4,155	4,157	4,101
Total	43,087	42,905	42,181

Table 7.--Amount of degrade occurring in each of four radially segregated groups of white fir lumber from four log positions after each stage of processing

Radial segregation	Log position ^{1/}				
	1	2	3	4+	All
----- Percent -----					
Rough-green to rough-dry:					
Center	12.0	6.6	13.9	14.5	12.3
Middle	23.8	12.7	10.3	12.7	15.7
Outer	22.1	16.9	19.9	21.4	20.2
Average, three segregations	19.4	13.2	16.1	17.1	16.7
Mixed	35.1	13.2	4.5	15.2	16.0
Average, all segregations	20.5	13.2	14.6	16.9	16.6
Rough-dry to surfaced-dry:					
Center	25.9	45.8	31.9	34.8	34.1
Middle	43.0	32.1	26.4	38.5	36.9
Outer	46.3	40.8	39.9	36.2	39.1
Average, three segregations	38.6	40.0	34.6	36.3	37.4
Mixed	26.4	8.8	36.7	41.1	33.9
Average, all segregations	37.7	38.3	34.9	36.9	37.0
Rough-green to surfaced-dry:					
Center	30.1	40.9	31.3	36.4	34.6
Middle	53.9	33.5	31.1	44.5	43.3
Outer	54.6	45.7	46.2	47.1	48.0
Average, three segregations	46.5	41.2	38.5	43.2	42.8
Mixed	44.2	15.4	39.8	46.8	41.2
Average, all segregations	46.3	39.8	38.7	43.6	42.5

^{1/} Log position in 16-foot log lengths from the butt.

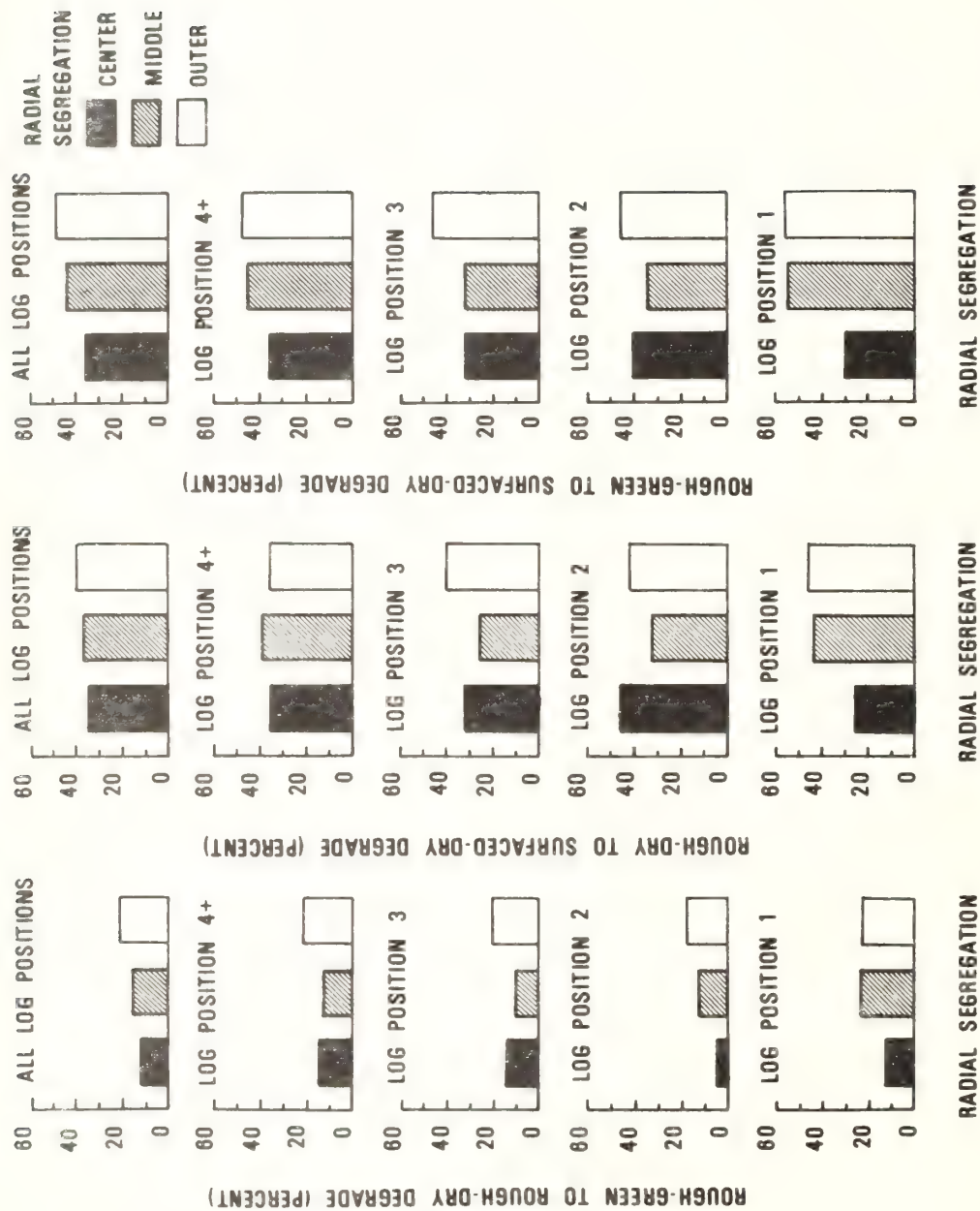


Figure 2.--Radial distribution of lumber degrade at various heights in white fir trees-- rough-green to rough-dry, rough-dry to surfaced-dry, and rough-green to surfaced-dry condition. Log position is in 16-foot lengths from the butt.

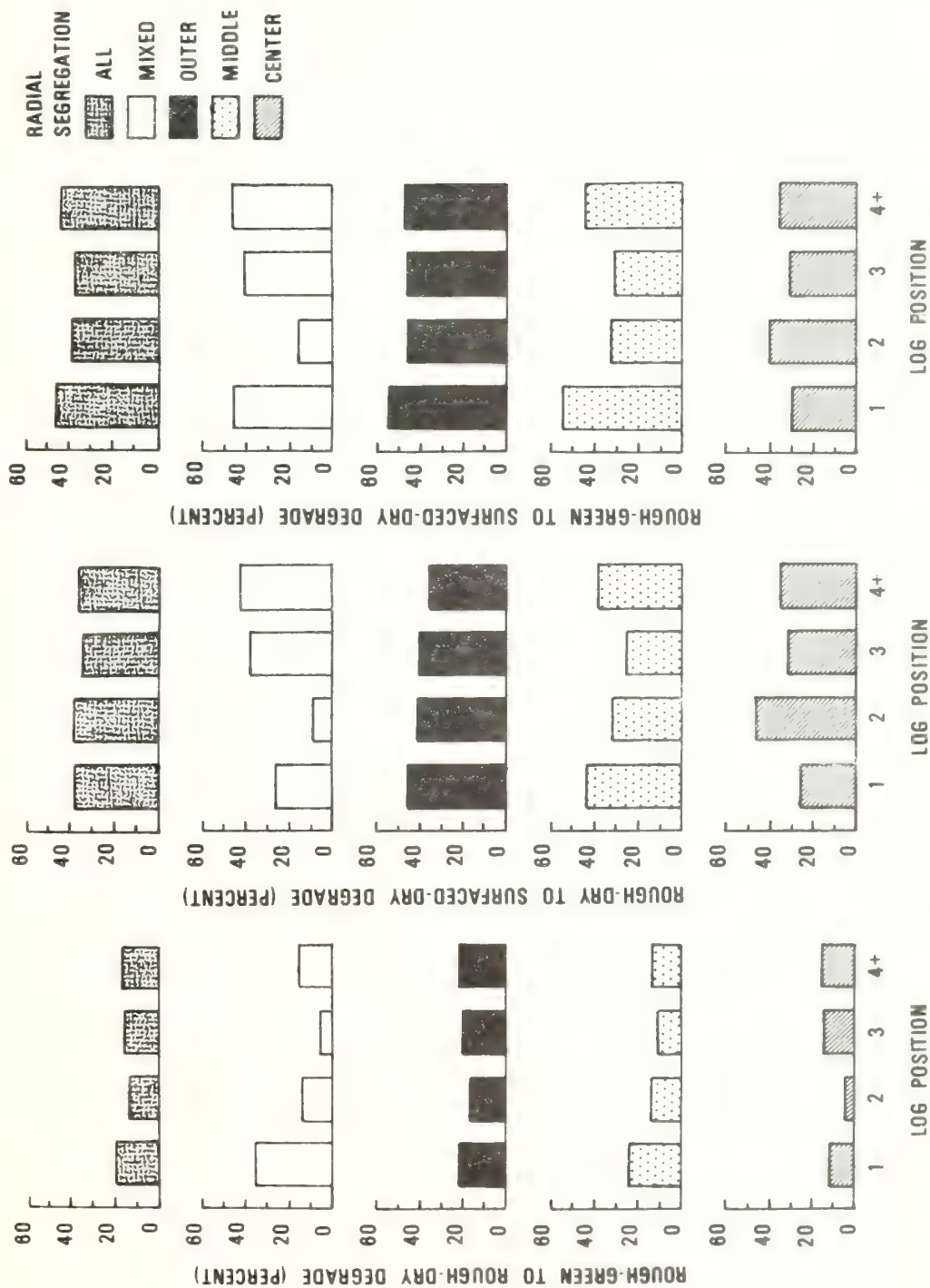


Figure 3.--Vertical distribution of lumber degrade of various radial segregations in white fir trees--rough-green to rough-dry, rough-dry to surfaced-dry, and rough-green to surfaced-dry condition. Log position is in 16-foot lengths from the butt.

Table 8 presents the degrade of three drying sorts of lumber, each from four log positions. Commercially the sorts are indicative of the time required to kiln-dry lumber, with the corky sort

requiring the shortest period, followed by the sap sort, and then the sinker sort (see table 4). The corky sort, which we found to come primarily from above the third log and radially from the center and

Table 8.--Amount of degrade occurring in each of three drying sorts of white fir lumber from four log positions after each stage of processing

Log position ^{1/} and drying sort	Processing stage		
	Rough-green to rough-dry	Rough-dry to surfaced-dry	Rough-green to surfaced-dry
- - - - - Percent - - - - -			
1:			
Sinker	15.4	38.0	43.5
Corky	<u>2/0</u>	<u>2/0</u>	<u>2/0</u>
Sap	22.2	44.2	63.8
Average	20.5	37.7	46.3
2:			
Sinker	12.0	36.4	38.8
Corky	<u>2/66.7</u>	<u>2/0</u>	<u>2/66.7</u>
Sap	16.7	44.1	46.2
Average	13.2	38.3	39.8
3:			
Sinker	18.5	36.2	42.0
Corky	2.3	16.3	16.3
Sap	13.1	41.3	43.3
Average	14.6	34.9	38.7
4+:			
Sinker	20.6	35.2	48.7
Corky	13.1	39.3	43.0
Sap	18.7	39.6	50.1
Average	16.9	36.9	43.6
All log positions:			
Sinker	15.0	37.0	42.0
Corky	11.6	36.0	39.2
Sap	17.2	40.8	48.4
Average	16.6	37.0	42.5

^{1/} Log position in 16-foot lengths from the butt.

^{2/} Degrade based on a drying sort volume of less than 100 board feet of lumber.

middle thirds (Wilcox and Pong 1971) (fig. 4), degraded less than either the sap or sinker sorts in all stages of processing except during the rough-dry to surfaced-dry stage, when this sort from the fourth and higher logs registered a higher de-

grade than the sinker sort. The sap sort registered higher degrade than the sinker sort at all stages of processing except during the rough-green to rough-dry stage, when the sinker sort from the third log and above showed a higher degrade.

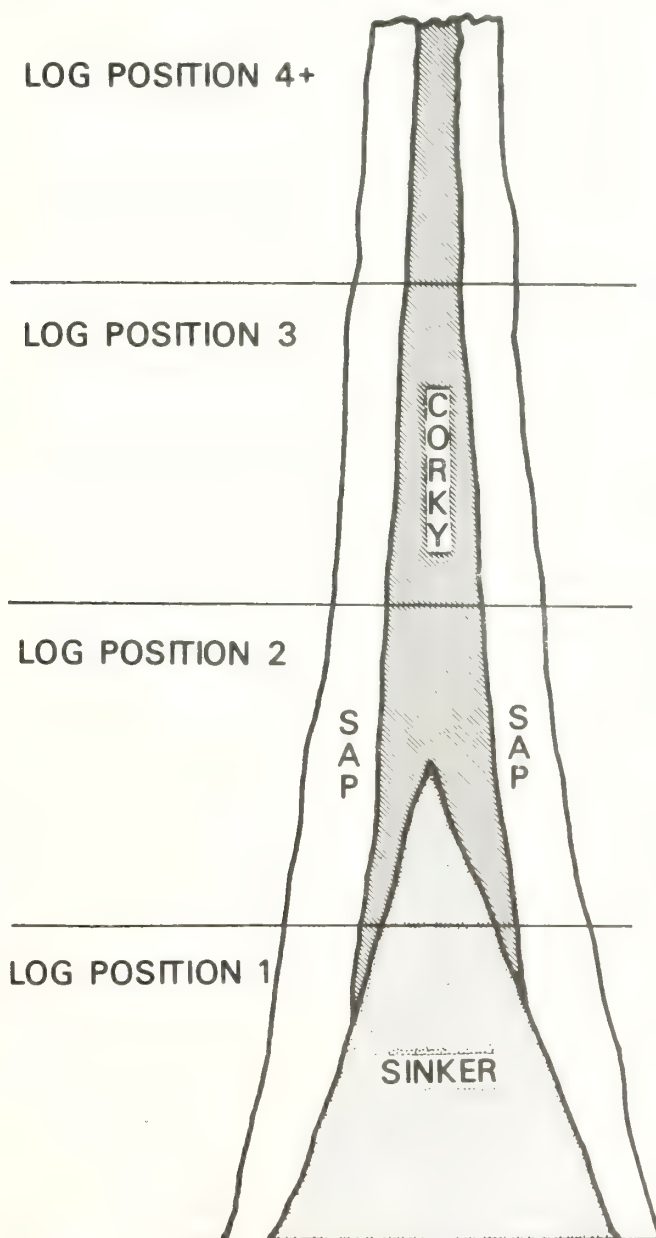


Figure 4.--Graphic representation of distribution of drying sorts in white fir trees, based upon earlier data (Wilcox and Pong 1971), mill observation, and statements of mill personnel. Log position is in 16-foot lengths from the butt.

The degrade of lumber from different grades of logs after each processing step is presented in table 9. All grade 1 logs were butt logs (log position 1) except for one second log (log position 2); grade 2 logs were composed of butt and second logs, and grade 3 logs were a mixture of logs from all positions. In general, lumber from grade 1 and 2 logs degraded more than the lumber from grade 3 logs. Since the logs in grades 1 and 2 included a substantial number of high quality, position 1 logs, it is understandable that the recorded lumber degrade for these grades of logs was similar to that recorded for position 1 logs, while the grade 3 logs, being a composite of logs from all log positions, averaged somewhat lower in degrade than the higher grade logs (table 7).

The recovery of various grades of lumber in the rough-green, rough-dry, and surfaced-dry condition for the four log positions and for the four radial segregations of lumber, respectively, are presented

in figures 5 and 6. As expected, the recovery of higher grades of lumber (Selects and Shops) was proportionately greatest from lower logs (fig. 5), with most of the production of these grades concentrated in the outer radial segregation (fig. 6). The recovery of Dimension grades of lumber, though proportionately less in the lower logs than upper logs, still made up the bulk of the lumber volume from all logs. In the upper logs, the recovery was almost entirely in the Dimension grades (fig. 5). Radially, the recovery of Dimension lumber was proportionately greatest in the center and middle radial segregations (fig. 6).

In the "mixed" radial segregation, also (fig. 6), the lumber recovery was mostly Dimension. The fact that these boards were color coded with three colors suggests that they were sawn from logs of small diameter. Our data indicate that most of these boards were from the small diameter, upper logs of the study.

Table 9.--Amount of degrade occurring in white fir lumber
sawn from different grades of logs after
each stage of processing

Log grade ^{1/}	Processing stage		
	Rough-green to rough-dry	Rough-dry to surfaced-dry	Rough-green to surfaced-dry
----- Percent -----			
1	19.9	40.5	46.8
2	14.7	42.7	46.5
3 ^{2/}	16.4	35.3	41.1
All logs	16.6	37.0	42.5

^{1/} See Wise and May (1958).

^{2/} Logs in this grade include high and low Commons.

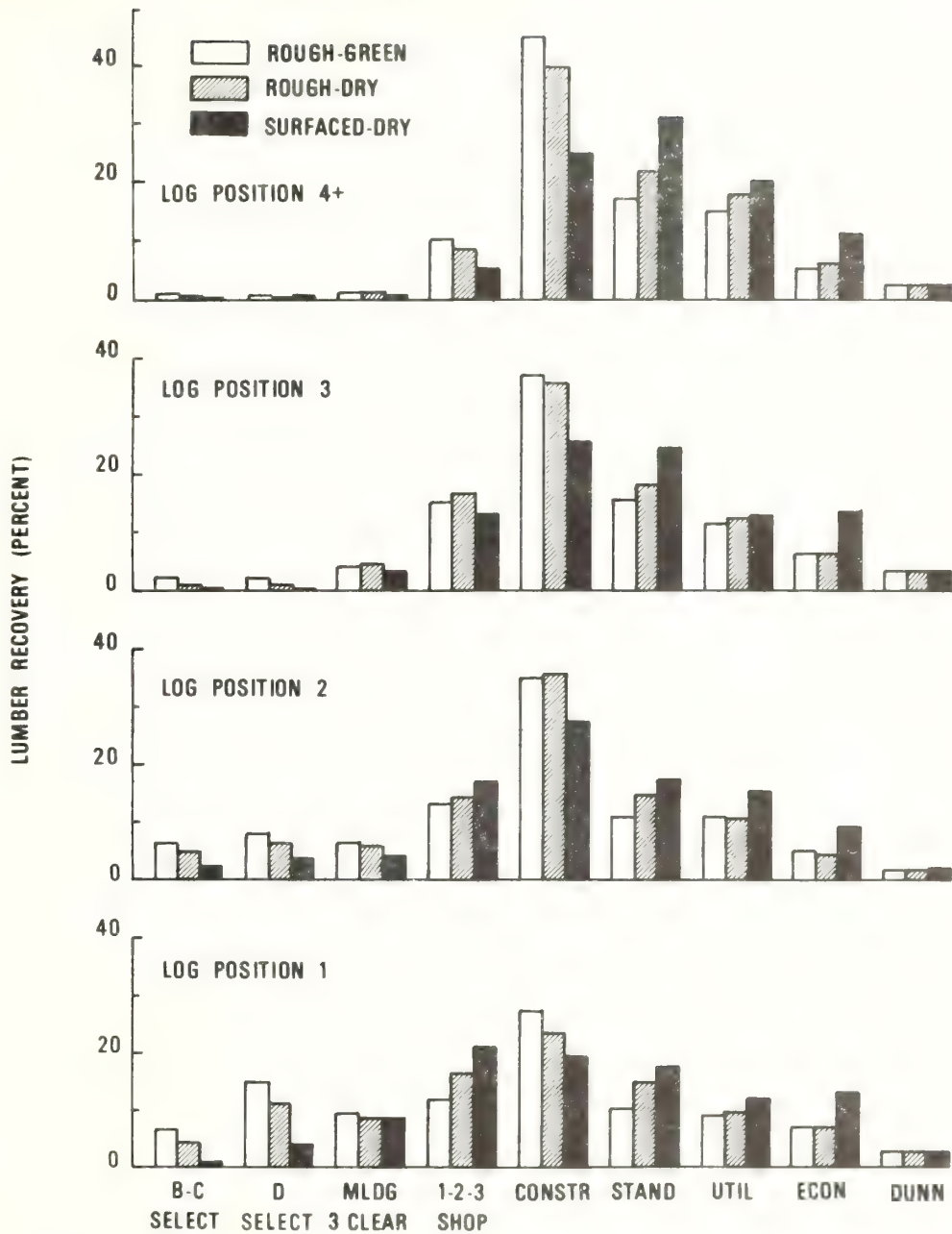


Figure 5.--Grade recovery of white fir lumber for four log positions in the rough-green, rough-dry, and surfaced-dry condition. Log position is in 16-foot lengths from the butt.

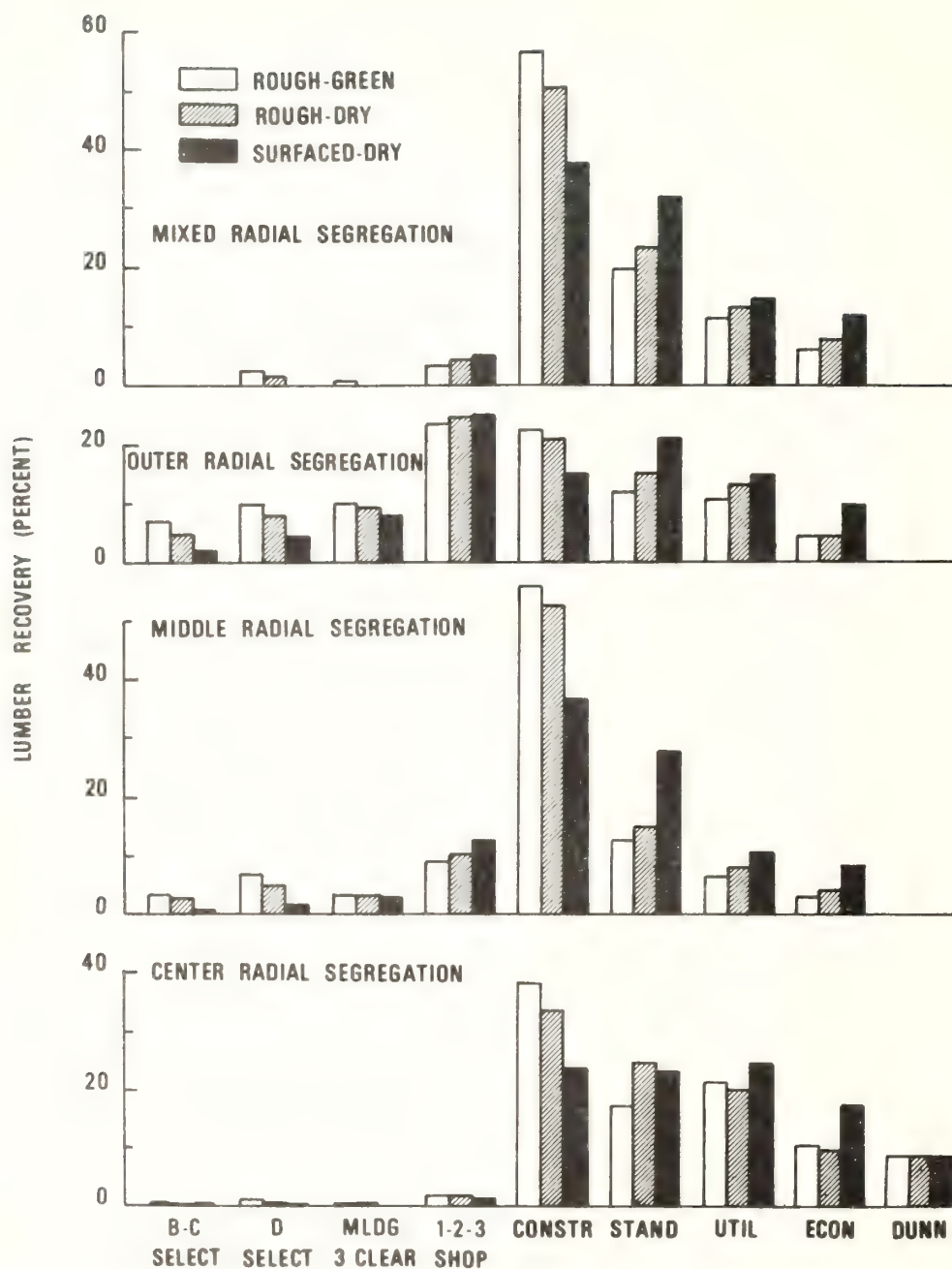


Figure 6.--Grade recovery of white fir lumber for four radial segregations in the rough-green, rough-dry, and surfaced-dry condition.

DISCUSSION AND CONCLUSIONS

We would like to emphasize that the results of this study apply only to the sample tested. Still, it is useful to draw from these data a number of conclusions with regard to the spatial distribution of lumber degrade and grade recovery on the belief that they may be fairly representative of white fir.

Though there was some variation in the degrade distribution pattern of the study lumber from the various log positions and in each of the radial segregations following processing (see table 7; figs. 2 and 3), a general pattern of degrade could be observed in the study trees. This pattern was one of increasing degrade from pith to bark in the radial direction, while in the vertical direction, degrade initially decreased and then increased with height.

The fact that greater degrade was generally recorded in the middle and outer radial segregations of lumber at all log positions following each processing stage suggests that the grade falldown could be due in part to the grade of lumber in these segregations. As previously reported (Pong 1971), higher grades of lumber tend to degrade more than lower grades of lumber due to more stringent grading rules applied to them. Examination of lumber grades recovered in the rough-green, rough-dry, and surfaced-dry condition by log position (fig. 5) shows that the Selects, Shops, and Dimensions all experienced some downward shifting of grade regardless of log position. What proportion these grades were of the total lumber volume for any one radial location, however, could influence the level of degrade at that location. Examination of the lumber recovery in each radial segregation (fig. 6) reveals that nearly all Shops and Selects produced

in this study were concentrated in the middle and outer radial segregations.

How uniform each of these segregations is with regard to drying sort may also have an influence on degrade. We found in previous work (Wilcox and Pong 1971) that drying sorts originate from different locations within white fir trees (fig. 4). The bulk of the sinker sort came from the center and middle radial thirds of the lowest two logs, commonly referred to as the wetwood zone (Wilcox 1968). Most of the corky sort came from the center and middle thirds of logs above the third log, and the sap sort came primarily from the middle and outer thirds of the logs above the second log. Such a distribution of drying sorts would suggest that the distribution of degrade, both radially and vertically, could be affected by the uniformity of the dry sort material from each location.

Since each sort requires different times to dry, the problems associated with drying boards in a given sort which contains material that actually belongs in more than one sort would be minimal in those segregations which are most uniform and greatest in those which are not. In actual practice, however, boards must be produced in standard sizes; and it frequently is not possible to saw them so that they contain material which will dry uniformly. Boards composed of material of more than one sort must be dried at the schedule appropriate for the material of the slowest drying rate, with the result that the faster drying material in the same board may be overdried.

According to this logic, the sap sort, which contains material primarily from the outer radial third of logs from all heights in the tree, would be expected to contain the greatest amount of mixed sort material and to have the highest degrade.

Similarly, boards from the center of lower logs (primarily sinker sort) and the center of upper logs (primarily corky sort) would be expected to contain material mostly of a single drying characteristic and, therefore, to have lower degrade than material from other locations. Both hypotheses appear to be borne out by the present data (tables 7 and 8).

Thus, the generally lower degrade registered by the center segregation of lumber (fig. 2) may reflect not only lower lumber grades but also a more uniform sort in this radial group of lumber. The higher degrade of the middle and outer segregations reflects a less uniform sort along with the observed higher grades of lumber in these segregations.

In upper, small-diameter logs there is less chance for boards to be of uniform sort. This may be reflected not only by the overall increase in degrade in the lumber from the fourth and higher logs but also by the relatively higher lumber degrade in each of the radial segregations (fig. 3, table 7) and in each of the drying sorts (table 8).

The fact that a significant difference in degrade was recorded between segregated groups of lumber at log position 1 following the surfacing of the rough-dry lumber (fig. 2) suggests that the lumber in the center segregation at this log position was of nearly uniform sort (sinker). Also suggested is that the middle and outer segregations contained not only pure sap boards but also boards of sinker-sap combination (fig. 4).

The significantly higher degrade registered by the center segregation of lumber at log position 2 in going from the rough-dry to the surfaced-dry condition suggests that this segregation was less uniform in its drying sort not only in

comparison to the other radial segregations at that log position (fig. 2) but also when compared to the center segregations of the other log positions (fig. 3). Because logs at this position may contain material of all three drying sorts (fig. 4; also Wilcox and Pong 1971), it can be assumed that the center segregation included not only boards of pure sinker material but also boards of sinker-sap, sinker-corky, and sinker-corky-sap combinations. It is interesting that the degrade of this particular segregation increased nearly sevenfold--6.6 percent to 45.8 percent (table 7)--between the stages of rough-green to rough-dry and rough-dry to surfaced-dry. This was the largest single change in degrade registered by any of the segregations of lumber included in the study.

The lower values of lumber degrade recorded in the middle and outer radial segregations at log positions 2 and 3 suggest greater uniformity in these segregations--corky in the middle, sap in the outer (see fig. 4)--in comparison to those at log position 1 (fig. 3, table 7). They also reflect the exceptionally low degrade of the corky sort (table 8) and the occurrence of lower grades of lumber in these radial segregations (figs. 5 and 6).

It is apparent from our discussion that a lack of uniformity in the composition of individual boards can significantly affect the magnitude and distribution of lumber degrade in white fir trees. Our results suggest that segregated groups of boards containing material of uniform drying properties degrade less than those of less uniform composition. These results confirm those reported by Smith and Dittman (1960b) in their work on drying rates of white fir. If what we suggest here is correct, wet-wood, as such, previously considered to be a source of lumber drying problems, has little or no effect on degrade.

The fact that significant differences in degrade were recorded in the lowest two logs places even greater importance on these logs than might at first be recognized. This is true not only because of the potential of these logs for producing the highest quality boards and nearly half the total lumber volume in the tree (Wilcox and Pong 1971) but also because it is in these logs that reducing degrade has its greatest potential, both in volume and value. This is particularly apparent when one realizes that in our sample the lowest two logs generally were the highest quality and produced the greatest quantity of upper grades of lumber, while at the same time producing the greatest amount of degrade (table 9).

Results of this study strongly suggest that decreased degrade might result if additional drying sorts were made in both the sap and sinker sorts. This would allow separation of boards of mixed composition

from those of uniform dry sort material. Such a separation would remove boards potentially high in degrade to a smaller group, which could then be dried under a different schedule, hopefully with much less degrade. This would also allow greater flexibility in improving the drying schedules for the residual, more uniform sorts of lumber, which in some cases are the highest quality boards--the sap sort in the lowest two logs.

This study has shown that examining degrade in relation to parameters apparent in standing white fir trees may help to identify within the tree troublesome locations producing lumber potentially high in degrade. Results of this study emphasize the need to recognize that many of our degrade problems may actually have their origin in properties of the raw material rather than being directly caused by processing.

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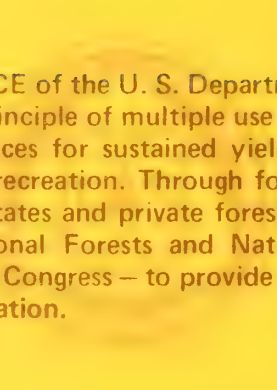
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**EFFECTS OF
AERIAL APPLICATION OF DDT
FOR TUSsock MOTH CONTROL
ON NESTLING SURVIVAL
OF MOUNTAIN BLUEBIRDS
AND HOUSE WRENS**



**JACK WARD THOMAS AND
D. CALVIN McCLUSKEY**

Abstract

Observations were made on 12 mountain bluebird (*Sialia currucoides*), 1 Western bluebird (*S. mexicana*), and 9 house wren (*Troglodytes aedon*) nests in northeast Oregon following aerial application of 0.75 lb per acre of DDT to control Douglas-fir tussock moth (*Orygia pseudotsugata* McDonnough). Nests were checked at intervals to determine if nestling mortality occurred from starvation due to a lack of insect food or direct DDT intoxication. Eggs laid, eggs hatched, and nestling survival were compared with control areas of 47 mountain bluebird, 9 Western bluebird, and 5 house wren nests. The majority of nests were located in nest boxes (350 boxes in nonspray and 200 in spray areas) erected to attract nesting birds for study. Spray was applied after egg laying and incubation were complete or underway. No significant difference in nestling survival between spray and nonspray areas was detected.

Keywords: DDT monitoring, bluebirds, house wrens, bird reproduction effects.

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Introduction

THE PROBLEM

During June-July 1974, 426,159 acres of forested land were sprayed with DDT in northeastern Oregon, southeastern Washington, and adjacent Idaho to control Douglas-fir tussock moth (*Orygia pseudotsugata* McDonnough). An environmental impact statement (USDA Forest Service 1973) gave the rationale on which the request to the Environmental Protection Agency (EPA) for DDT use was based. The agency had previously banned DDT for this use.

EPA gave approval but required intensive monitoring, of which this study was a part.

We sought to determine if DDT application had adverse, short-term effects on reproductive performance of insectivorous birds. Because of time and resource limitations, we further limited the study to cavity-nesting, insectivorous birds.

CHEMICAL APPLICATION

DDT (0.75 lb) mixed with 0.94 quart of auxiliary solvent and enough No. 2 fuel oil to make 1 gallon was sprayed from helicopters at approximately 0.75 lb DDT per acre. This rate was applied to 420,944 acres including our study areas. Another 2,530 acres were sprayed at 0.50 lb per acre and 3,085 acres, at 0.25 lb per acre. The spray was shut off over grassland openings of more than 2 acres (Rod Canutt, Monitoring Coordinator, personal communication) which was important because many insectivorous bird species feed there.

Methods

NEST BOXES

Nest boxes were constructed similar to Schutz' description (1974, p. 132) and placed at minimum intervals of 200 feet to attract cavity-nesting birds, particularly mountain bluebirds (*Sialia currucoides*), Western bluebirds (*S. mexicana*), and house wrens (*Troglodytes aedon*).

SPECIES SELECTION

Mountain bluebirds, Western bluebirds, and house wrens were selected because:

1. They are insect feeders with 90 percent or more of the spring and summer diet composed of insects (Martin et al. 1951, Beal 1915, Bent 1948, 1949, and Knowlton and Harmston 1946).
2. They commonly nest within the outbreak areas (Gabrielson and Jewett 1940).
3. They are cavity nesters and can be attracted to nest in boxes (Headstrom 1970, Gabrielson and Jewett 1940, Peterson 1961).

4. Their preferred habitat is open conifer woodland or ecotones between forest edge and grassland openings as depicted in figure 1 (Gabrielson and Jewett 1940, Peterson 1961).

5. They nest 4 to 6 feet above the ground (Headstrom 1970).



Figure 1.--Typical ecotone habitat between mixed conifer and grassland openings where nest boxes were located.

The foregoing were important, respectively, because:

1. The study concerned cavity-nesting, insectivorous birds; the chance to study several species provided a "fail safe" mechanism that increased the likelihood that data would be obtained.

2. The more common the species, the greater the likelihood of obtaining adequate samples.

3. Bird boxes attract birds to areas easily reached by us and the contents could be easily inspected.

4. The forest-grassland could be easily followed on the ground and seen on aerial photographs, greatly facilitating both finding the boxes and checking them.

5. Nests could be examined without climbing (fig. 2).

Figure 2.--Nest boxes were located at a height suitable for easy examination.



REPRODUCTIVE SUCCESS

Boxes were checked at intervals ranging from 2 to 21 days with variations due to spray schedules and weather. Boxes were opened (fig. 3) on each visit and the contents described as follows:

1. Number of eggs (fig. 4).
2. Condition of eggs--broken, whole, or pipped.
3. Number of young (fig. 5).
4. Condition of young--alive or dead, physical condition.
5. Approximate age of young--0, 25, 50, 75, and 100 percent of fledging size.
6. Number of young fledged.

Reproductive success for each species was measured and compared as follows.

1. The mean of the eggs laid per clutch was compared between spray and nonspray areas using the t-test.
2. Egg fertility of spray and nonspray areas was compared by tabulating hatched and unhatched eggs and testing comparability by means of chi-square.

Numbers of eggs laid and egg fertility were not influenced by DDT due to the time

Figure 3.--Bird boxes were constructed so that they could be opened for easy examination of the contents.



Figure 4.--The number of eggs and their condition were determined by careful examination.

Figure 5.--Nestlings were counted and their age and physical condition determined.



of spray application. These measures of reproductive performance were compared for spray and nonspray areas only to give some measure of the comparability of the areas. Reasons for any differences were not known, but differences were not associated with current DDT spray.

3. Nestling mortality was determined by counting dead young and assuming others had flown the nest; results for spray and nonspray areas were compared by the chi-square.

4. Fledging was assumed when the nest previously containing young was no longer occupied, they were healthy at last examination, they would have been developed enough to depart, and no dead young were found in the box or nearby. Such data were circumstantially derived. So, nestling survival in spray areas was also examined by determining the known days young survived postspray. We emphasize that fledging data are circumstantially derived, unless the young are actually observed leaving the nest. Just how much faith should be placed in the assumption of fledging is debatable. The probability of the interpretation of fledging being correct was probably related to the time elapsed between the last nestling examination, the assumed fledging date, and the time lapse from that date to the next examination.

So, probable hatching and fledging dates were derived from the "best estimator" available from the field data. For example, if the eggs were in the process of hatching when the nest was examined, this was taken as the best estimator of the hatching date. Then 16 days (Bent 1948 and 1949) were counted from that date to derive the probable fledging date.

The ages or sizes of the nestlings were estimated as 0, 25, 50, 75, or 100 percent of fledging age or size. This crude index was also used, in the absence of other data, as best estimator of hatching and fledging dates. Probable hatching and fledging dates were derived by counting forward and backward from the last date the nestlings were observed, allowing 4 days per 25-percent size or age class. For example, if the young were at 75 percent of fledging stage on last examination, the hatching date was derived by counting back 12 days and, conversely, estimating the fledging date by counting forward 4 days.

5. The chronology of activities in each nest was displayed and scrutinized for patterns and data deviation.

DDT REACHING GROUND LEVEL

DDT reaching the ground was measured from three 4- by 5-inch oil-sensitive cards (White 1959) placed near each box 12 to 24 hours before and removed 12 to 24 hours after spray application. No cards were placed on boxes in the nonspray areas. Boxes were located in the forest-grassland ecotone; and we sampled at the box, 60 feet from the box, in the open, and a like distance inside the wooded area for an estimate of the DDT delivered at ground level to the area. Cards were placed at ground level at the prescribed point. Many cards were under shrubs or surrounded by grasses.

Cards were analyzed as described by Maksymiuk (1963a) and Davis and Elliott (1953).

The mean value of the cards was considered the DDT level at that box. We assumed that the DDT estimate was representative of that territory. These levels were considered critical, as wrens and bluebirds are said to feed primarily on ground-dwelling insects (Martin et al. 1951).

Data on an additional 490 card distributed over our study areas to check the overall spray results were made available by the U.S. Forest Service, Region 6.

INSECT RESPONSE TO DDT APPLICATION

Insect response to DDT was estimated from malaise-type net traps described by Butler (1965) and shown in figure 6. Two were placed near each cluster except for the two McAllister Ridge clusters which had one each. The measure of flying insect population was the biomass trapped per trap per day (fig. 7). This was considered as a crude index of the general insect population. Such traps operated in New York (Matthews and Matthews 1970) captured the following orders: Diptera (44.7 percent), Plecoptera (20.8), Hymenoptera (14.7), Lepidoptera (7.2), Hemiptera (7.1), and Coleoptera (2.4). We emphasize that such traps trap flying insects and not the ground-dwelling insects on which bluebirds and house wrens feed. Thus we considered these data only a crude index of the effect on insects as a whole.

Figure 6.--Malaise insect traps were used to obtain relative measures of the flying insect population. A side of the net has been removed to make it function like a backstop. Insects fly into the net and then continue to fly upward until they enter the plastic bag where they are killed by an insecticide.



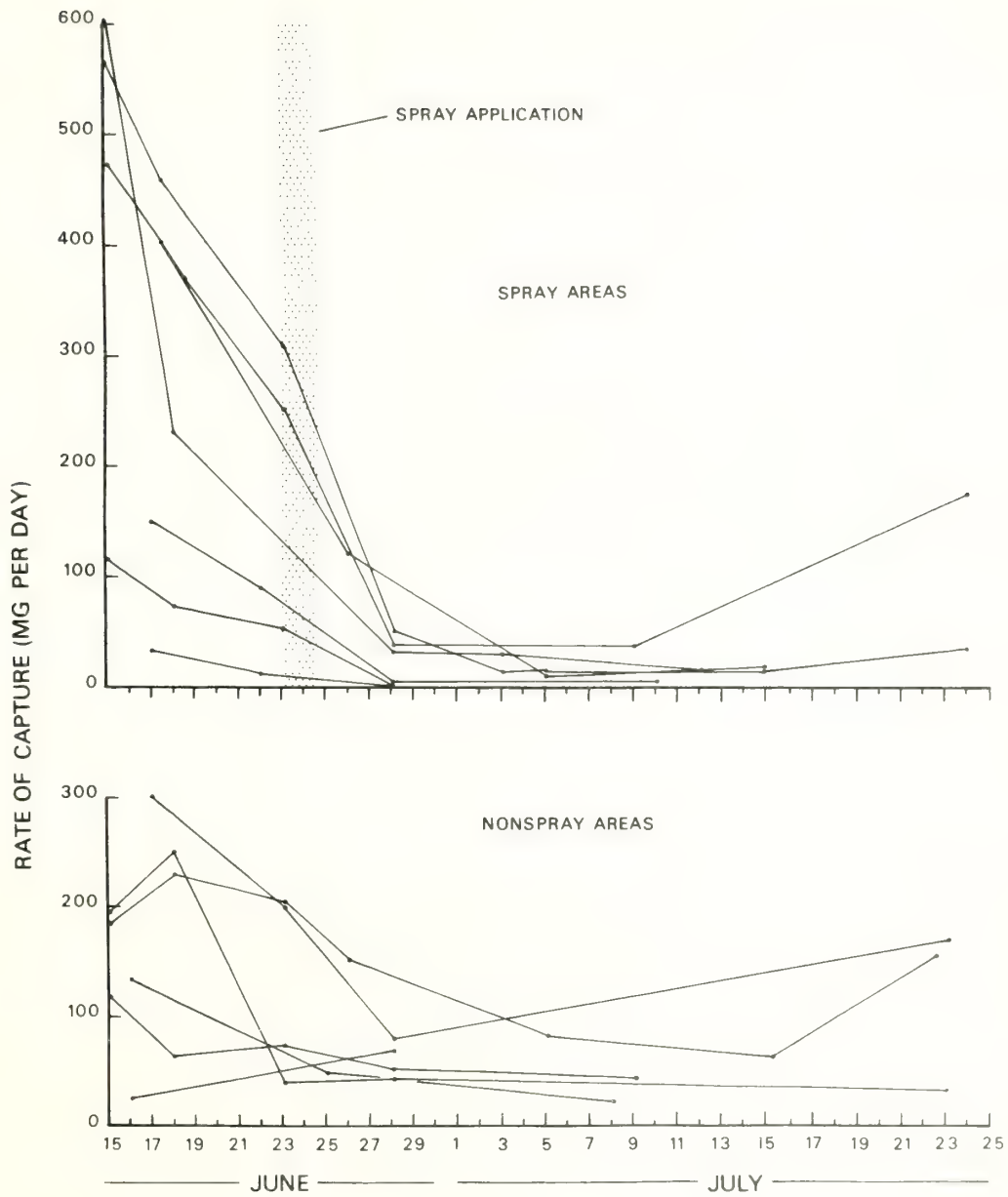


Figure 7.--Rate of insects trapped over time.

INSTALLATION OF BIRD BOXES

Between April 26 and May 22, 1974, 550 nest boxes were installed in 11 clusters of 50 boxes each (table 1) while spray areas were still tentative. Six clusters were in designated spray areas and five in other areas.

As a result of late changes in the spray program, 4 clusters (200 boxes) were sprayed and 7 clusters (350 boxes) were not. Sprayed clusters were separated from controls by at least 0.5 mile. Operational restrictions on wind velocities suitable for spraying made it probable that spray drift did not occur between areas.

Results

DATA TREATMENT

The total data on which the remainder of the paper is based are given in appendixes 1-16. Mountain bluebird nest data for the spray areas are treated in appendix 1 and for control areas in appendix 2. Similar data for house wrens is given in appendixes 3 and 4, and for Western bluebirds in appendixes 5 and 6. Summaries are shown in table 2. The data for each nest for each species was arranged in a display depicting event chronology (appendixes 7 and 8 for mountain bluebirds, 9 and 10 for house wrens, and 11 and 12 for Western bluebirds).

In most cases, DDT was applied after clutches were complete (appendixes 7, 9, and 11 and fig. 8) and would not have influenced clutch size or egg fertility. However, the data were tested to examine comparability between spray and nonspray areas to detect if habitat attribute(s) might have affected these reproductive measures. Clusters were ignored as a variation source due to small numbers available for testing.

CLUTCH SIZE

Clutch size for mountain bluebirds averaged 5.3 in the spray area and 5.2 in the nonspray area. Results of t-test ($t = 0.5840$, degrees of freedom = 57, $p = 0.05$) indicated no significant difference in means.

For house wrens, the clutch averages were 6.7 in the spray area and 5.4 in the nonspray area, and they were significantly different ($t = 2.4010$, degrees of freedom = 12, $p = 0.05$). The reason for this difference was not known, but it was not connected with DDT.

EGG FERTILITY

Fertility of areas was compared by the number of eggs hatched and failed to hatch. For mountain bluebirds (appendixes 1 and 2) the chi-square test for independence with correction for continuity revealed ($\chi^2 = 0.65$, degrees of freedom = 1, $p = 0.05$) no significant difference.

For house wrens (appendixes 3 and 4), the same test revealed no significant difference in egg fertility ($\chi^2 = 0.27$, degrees of freedom = 1, $p = 0.05$).

Table 1.--Location and description of nest box clusters--50 boxes per cluster (total 550 boxes),
northeastern Oregon, 1974

Cluster	Cluster name	Date installed	Boxes occupied		Treatment	County	Section
-Number- -Percent-							
1	Fox Prairie	April 26	4	8	Nonspray	Umatilla	26,35,36
2	Y Ridge	April 29	10	20	Nonspray	Umatilla	6,7
3	Spring Creek	April 30	6	12	Nonspray	Union	21,27,28
4	Interstate	May 1	3	6	Nonspray	Union	26,27
5	Starkey Ridge	May 3	8	16	Nonspray	Union	11,12,14,21
6	Sled Springs	May 6	6	12	Nonspray	Wallowa	25,26
7	Starvation Ridge	May 7	13	26	Nonspray	Wallowa	7,13,18
8	McAllister	May 8	4	8	Spray	Wallowa	12,13,18
9	McAllister Ridge	May 10	4	8	Spray	Wallowa	19,30,31
10	Horseshoe Ridge	May 13	10	20	Spray	Umatilla	18,20,29
11	Powatka Ridge	May 22	2	4	Spray	Wallowa	21,28
All boxes			<u>17</u>	<u>13</u>			

^{1/} This does not include 13 natural nests that were considered in the total of 83 nests that were reported in the study.

Table 2.--Summary comparison of reproductive performance

Species and area	Number of nests	Eggs ^{1/}						Young			
		Total		Hatched		Failed		Died		Assumed fledged	
		No.	Average	No.	Average	No.	Average	No.	Average	No.	Average
House wrens:											
Spray	9	60	6.7	53	5.9	7	0.8	0	0	53	5.9
Nonspray	5	27	<u>5.4</u>	22	<u>4.4</u>	5	<u>1.0</u>	6	<u>1.2</u>	16	<u>3.2</u>
Difference ^{2/}			-1.3		-1.5		+2		+1.2		
Mountain bluebirds:											
Spray	12	63	5.3	61	5.1	2	.2	0	0	61	5.1
Nonspray	47	246	<u>5.2</u>	229	<u>4.9</u>	17	<u>.4</u>	0	<u>0</u>	229	<u>4.9</u>
Difference ^{2/}			-.1		-.2		+2		0		
Western bluebirds:											
Spray	1	6	6.0	5	5.0	1	1.0	0	0	5	5.0
Nonspray	9	44	<u>4.9</u>	44	<u>4.9</u>	0	<u>0</u>	0	<u>0</u>	44	<u>4.8</u>
Difference ^{2/}			-1.1		-.1		-1.0		0		

^{1/} Because of the timing of spray application, it was not possible for DDT to be involved in any differences in the numbers of eggs laid and eggs hatched.

^{2/} Nonspray minus spray.

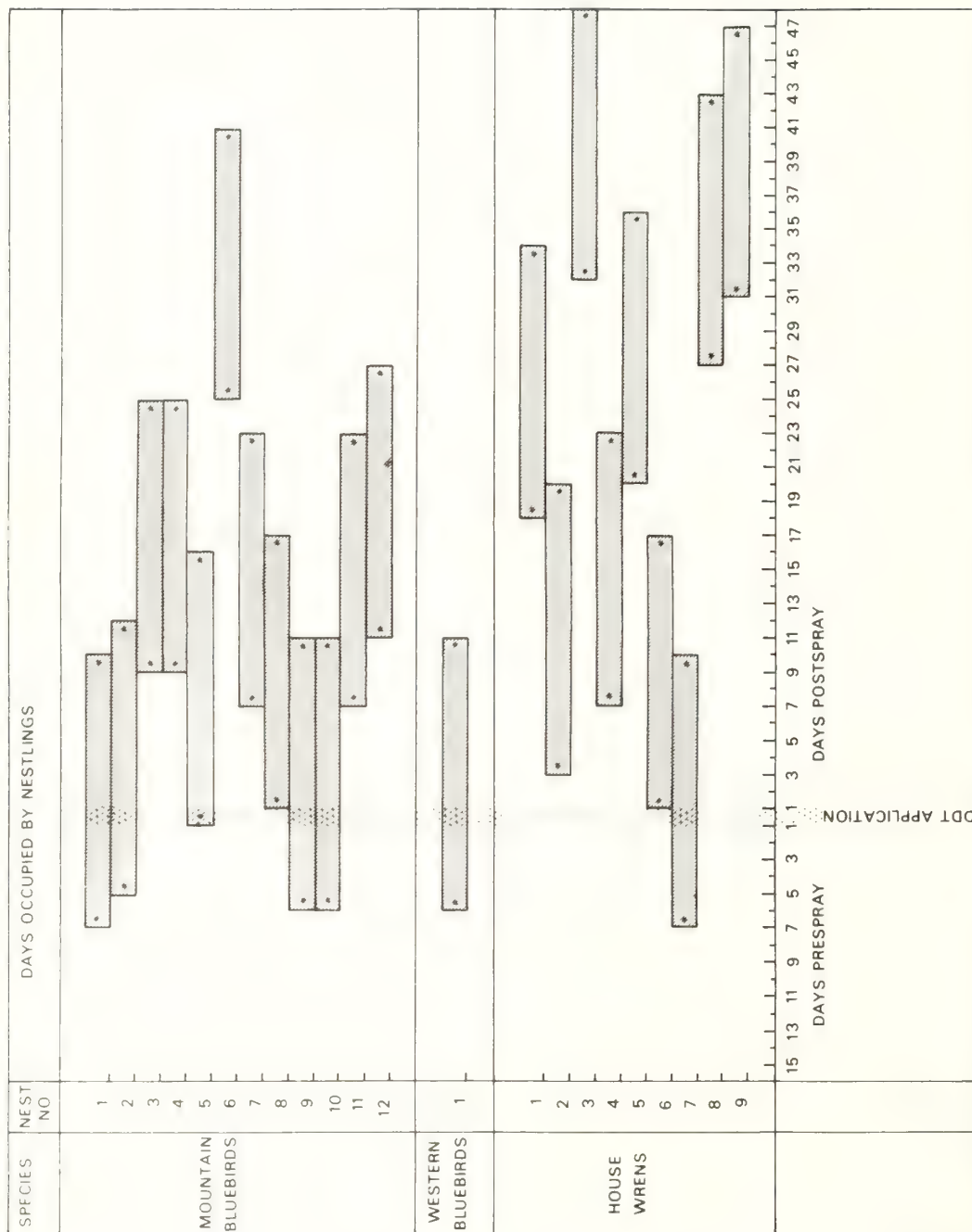


Figure 8.--Hatching and fledging dates and nest occupancy dates related to timing of DDT application. (Based on assumption of 16 days between hatching and fledging.)

NESTLING SURVIVAL

If DDT application affected reproductive performance, it could be demonstrated here only in terms of nestling survival. DDT was applied after the probable hatching dates for most of the nestlings observed in the spray areas (appendixes 7, 9, and 11, and fig. 8).

Power (1966) stated that mountain bluebirds demonstrated territorial behavior, flying up to one-quarter mile from their nests. Kendeigh (1941) reported that house wren territory varied with population level and averaged about 1 acre. He also stated that the wrens rarely left their territory during breeding season. Converting to the radius of a circle, we obtained 118 feet for travel from the territory center.

It was unlikely that many, if any, parents tending boxes in the spray areas traveled to nonspray areas to feed unless territories were expanded. We noted intense postspray feeding in areas of close proximity to the nest boxes. Distances from occupied boxes to nonspray areas ranged from 0.5 to 1.5 miles ($\bar{x}$ = 1.08) for mountain bluebirds, from 0.4 to 1.13 miles ($\bar{x}$ = 0.82) for house wrens, and was 0.75 mile for the Western bluebird.

There were no nestling losses detected for mountain bluebirds, in either spray or nonspray areas (table 2).

In the case of house wrens, no nestling deaths were recorded among 53 young in 9 nests, and the average fledged per nest was 5.9 (table 2). As performance in terms of nestling survival was perfect, it was obvious that DDT had no adverse influence in this regard. This precluded the necessity to test results against those from nonspray areas.

Fledging data were circumstantially derived, i.e., the absence of young birds, dead or alive, was taken to mean the birds fledged. However, more concrete information was known (days of nestling survival post-DDT exposure), which was derived from the chronological nesting events (appendixes 7, 9, and 11).

After DDT exposure, 56 mountain bluebird nestlings survived a total of 560 days (ranging from 3 to 21 days) (table 3) without mortality. With house wrens, 28 nestlings survived 238 days (ranging from 6 to 12 days) (table 4) without loss. Five Western bluebird nestlings survived 15 days of exposure (table 5) without mortality. These data are presented merely to give some indication of the confidence that could be placed on the circumstantially derived estimates of young fledged in spray areas. The fact that no young died during those periods when losses could be detected with certainty supports assumptions made concerning no losses before fledging. Comparison of similar data from nonspray areas was inappropriate. Performance in spray areas by this criterion was perfect, and such comparison was academic.

LATE VS. EARLY NESTING

All three bird species involved were reported to nest twice (Bent 1948, 1949). Mitchell et al. (1953) indicated significant adverse effects of DDT on reproduction of bluebirds and house wrens in second or late nesting.

Table 3.--Known days of survival for mountain bluebird
nestlings after DDT exposure

Nest	Young observed	Days between observations	Total survival days ^{1/}
<i>Number</i>			
1	6	11	66
2	5	11	55
3	4	11	44
4	5	11	55
5 ^{2/}	3	21	63
	2	11	22
6	4	7	28
7	5	10	50
8	6	11	66
9	5	3	15
10	6	11	66
11	5	6	30
12 ^{3/}	--	--	--
Total	56	--	560

^{1/} Total survival days = young observed x days between observations.

^{2/} The 2 sets of data for 1 nest result from the first observation showing 3 young and 2 eggs, the second observation 11 days later revealing 5 young, and the next, after another 10 days showing 5 young. Therefore, 3 birds were known to survive 21 days (3 birds x 21 days = 63 survival days) and 2 for 11 days (2 birds x 11 days = 22 survival days).

^{3/} Because of the particular circumstances of chronology of development and observation, the young in this nest were not observed. Therefore, there are no known number of survival days.

Table 4.--Known days of survival for house wren
nestlings after DDT exposure

Nest	Young observed	Days between observations	Total survival days ^{1/}
<i>Number</i>			
1	6	10	60
2 ^{2/}	--	--	--
3	5	6	30
4 ^{3/}	3	10	30
	2	8	16
5	3	10	30
6 ^{2/}	--	--	--
7	3	12	36
8 ^{2/}	--	--	--
9	6	6	36
Total	28	--	238

^{1/} Total survival days = young observed x days between observations.

^{2/} Because of the particular circumstances of chronology of development and observation, the young in this nest were observed only once. Therefore, there were no known number of survival days.

^{3/} The 2 sets of data for 1 nest results from the first observation revealing 3 young and 2 unhatched eggs and the second observation 2 days later showing 5 young. The last observation before fledging was made 8 days later and revealed 5 young. Therefore, 3 birds were known to have survived 10 days (3 birds x 10 days = 30 survival days) and 2 birds survived for 8 days (2 birds x 8 days = 16 survival days).

Table 5.--Known days of survival for Western bluebird
nestlings after DDT exposure

Nest	Young observed	Days between observations	Total survival days ^{1/}
<i>Number</i>			
1	5	3	15

^{1/} Total survival days = young observed x days between observations.

We wanted to know if there were differences in the amount of late or second nesting between sprayed and nonsprayed areas. Power (1966) suggested, from studies in Montana, that nests started after July 1 were late nests. All nests were classified, by this criterion, as early or late nests using the chronology displays (appendixes 7-12).

These data are shown in tables 6 and 7. Testing was performed by means of chi-square in a test of independence with correction for continuity.

Results were: mountain bluebirds $\chi^2 = 0.09$ and species pooled $\chi^2 = 0.27$. Degrees of freedom were 1 in each case, and the null hypothesis ($p = 0.05$) was accepted in both cases. There were no differences in late nesting activity between spray and nonspray areas. Such tests for house wrens and Western bluebirds were inappropriate due to too few entries and zero cells.

DDT LEVELS IN THE SPRAY AREA

DDT spray reaching ground level around bluebird boxes averaged 0.220 gal per acre, ranging from 0.008 to 0.726^{1/} for the three-card series at each box; averages were 0.090 inside the forest canopy, 0.180 at the forest edge, and 0.408 in the open (appendix 13).

For house-wren-occupied boxes, the average DDT spray level was 0.085 gal per acre, ranging from 0.008 to 0.280 with 0.057 inside the forest canopy, 0.076 at the edge, and 0.105 in the openings (appendix 14). The differences in the means for DDT levels were not significant between mountain bluebird and house wren nests ($p = 0.05$, $t = 1.4451$, d.f. = 18).

The DDT spray values for the one sprayed, Western bluebird nest were unknown inside the forest, 0.100 at the edge, and 0.300 in the opening (average 0.200).

The data for DDT spray reaching ground level at all boxes are in appendix 15.

Other cards were placed across openings of over 2 acres (openings of lesser size were sprayed) to judge if they received spray. The openings did receive widely variable amounts of spray (generally less than forested areas), and birds within sprayed areas had little access to DDT-free areas within our study boundaries. Yet, there were probably some grasslands within the spray area having very low DDT levels.

Data made available from 419 cards that were placed in these areas by other monitoring team members to judge overall spray patterns indicated an average of 0.24 gal DDT spray per acre reached ground level.

^{1/} These data were not considered accurate beyond two decimal points. These figures resulted from interpolation between standard test cards.

Table 6.--*Distribution of nests started after July 1
by area and species*

Species and nest start	Area		
	Nonspray	Spray	Total
----- Number -----			
Mountain bluebird:			
Early	39	11	50
Late	8	1	9
Total	47	12	59
House wren:			
Early	4	6	10
Late	1	3	4
Total	5	9	14
Western bluebird:			
Early	7	1	8
Late	2	0	2
Total	9	1	10
All:			
Early	50	18	68
Late	11	4	15
Total	61	22	83

Table 7.--*Nests included in the late nest category^{1/}*

Species	Area	
	Nonspray	Spray
Mountain bluebird	6, 9, 16, 20, 29, 31, 37, 47	6
House wren	1	3, 8, 9
Western bluebird	1, 5	

^{1/} Nest identification numbers correspond to those found in all tables and appendixes containing nest data.

The amount of DDT that reached ground level was a fraction of the 0.75 lb per acre thought to have been applied (table 8). In the case of occupied mountain bluebird boxes, 22.0 percent (0.165 lb per acre) of the application rate reached ground level compared with 8.5 percent (0.063 lb per acre) for house wrens. The percentage for all occupied boxes was 16.6 percent.

Tarrant et al. (1972) reported that the aerial application of 0.75 lb per acre of DDT on vegetatively similar areas near Burns, Oregon, resulted in 26.0 percent (about 0.195 lb per acre) of the DDT reaching the soil surface under forest canopy. This was not markedly different from the levels recorded in this study.

Strickler and Edgerton (1970), working in the same area under various canopy cover situations (29, 52, and 57 percent), reported that 46.7, 49.3, and 45.3 percent, respectively, of the application rate of 0.75 lb DDT per acre reached ground level.

There was a marked increase in spray reaching the ground from inside the canopy toward the opening (table 8). Maksymiuk (1963b) indicated that locations such as those we used for our cards at the forest edge and 60 feet toward the opening were still subject to screening by tree cover, with 16 to 43 percent of the spray that reached the ground 180 feet from the nearest tree being screened out. He commented that, "It can be that there is little or no screening effect when cards are placed at distances greater than three tree heights away from the nearest tree. However, at shorter distances the deposit on the cards is not a true measure of that on the surrounding forest area."

Table 8.-- Spray and DDT reaching ground level^{1/} at occupied boxes and clusters

Location ^{2/}	In forest		At box		In open		Total	
	Gal per acre	DDT per acre ^{3/}	Gal per acre	DDT per acre ^{3/}	Gal per acre	DDT per acre ^{3/}	Gal per acre	DDT per acre ^{3/}
Occupied boxes:								
Mountain bluebirds	0.090	0.067	0.180	0.135	0.408	0.306	0.220	0.165
House wrens	.057	.042	.076	.057	.105	.078	.085	.063
Combined	.069	.051	.129	.096	.281	.210	.166	.124
Clusters--all boxes:								
Powatka Ridge	.150	.112	.106	.079	.182	.136	.146	.109
McAllister Ridge	.074	.055	.086	.064	.278	.208	.134	.100
Horseshoe Ridge	.077	.057	.084	.063	.097	.072	.088	.066
McAllister	.061	.045	.114	.085	.325	.243	.174	.130
Combined	.089	.066	.097	.072	.208	.156	.131	.098

^{1/} See appendixes 13, 14, and 15 for details.

^{2/} Occupied boxes were included in the data for clusters, as DDT was applied after bird occupancy selections and was not influenced by spray application.

^{3/} DDT per acre = (gal per acre) (0.75 lb DDT per gal).

RESPONSE OF INSECT POPULATIONS TO DDT SPRAY

Data on insect matter obtained from malaise traps are shown in figure 7 and appendix 16. The trapping rate declined, in general, on both areas from samples taken in mid-June to the last ones taken before spray application on June 23 and 24.

However, when the last samples before spray were compared with first postspray samples, a marked difference in percentage population decline was evident between spray (80.7 percent) and nonspray areas (41.9 percent). Further, the mean milligram per trap per day of insect matter in the spray area was 48.0 percent of that in nonspray area immediately after spray application (37 vs. 77 percent).

These data are merely an index to general insect populations. There was a decline in this measure of the insect population probably due to DDT; this depression extended from June 23 and 24 to at least July 15, coinciding with that period when most nests contained nestlings being fed insects (fig. 7).

OBSERVATIONS

An immature robin (*Turdus migratorius*) and an unidentified nestling were found dead following spraying; none were found on the control areas.

Discussion

DDT could not have had an influence on the number or fertility of eggs, as DDT was applied after eggs were laid. If adverse effects were to be detected, it would have been in the form of nestling mortality.

Spray was applied, in most cases, after laying was complete (fig. 8). We detected no adverse effect of the aerial application of DDT on nestling survival of mountain bluebirds and house wrens.

Mitchell et al. (1953) showed fledging success of house wrens was 28 percent with such spray timing compared with 86 percent in unsprayed areas, while earlier pre hatch spray had little effect. The application rate in this study was 25 percent of the 3 lb per acre in the Mitchell et al. (1953) study where nest boxes were located in open fields insuring that more DDT reached ground level. In spray application on forested areas, spray reaching the ground would be less. In view of these differences our results are perhaps, not surprising.

The success (percent of eggs hatched and percent young fledged) of the nests we observed seemed inordinately high. When it was considered that we detected no adverse effects of DDT, data for the areas were pooled. Results are shown in table 9. In total, 92.8 percent of the eggs hatched, and 91.4 percent of the eggs resulted in fledged birds.

Hole nesters have been reported to have a decided advantage over open nesters in the percentage of eggs that result in fledging (Beebe 1974). Our fledging levels are greater than the 65 percent success for hole nesters indicated by Nice (1937) and the 66 percent (based on a sample of 94,400 eggs) reported by Nice (1957).

Table 9.--*Success rates--percentages of eggs hatched and eggs resulting in fledged young*

Species	Number of:			Percent hatched	Number fledged	Percent fledged ^{1/}
	Nests	Eggs	Hatched			
House wren	14	87	75	86.2	69	79.3
Mountain bluebird	59	309	290	93.8	290	93.8
Western bluebird	10	50	49	98.0	49	98.0
All	83	446	414	92.8	408	91.4

^{1/} As a percentage of eggs laid.

One or a combination of two factors may be involved: (1) nest boxes are even more effective than natural cavities in enhancing reproductive success or (2) our assumptions concerning fledging may not be correct.

Because the hatching rate (92.8 percent), which was actually observed and therefore verified, was also decidedly higher than the average of 73 percent reported for hole nesters by Kalmbach (1939), we believe the high success to be related to nest box protection.

Our results on survival were tabulated on the basis of nestling survival. All nestlings examined appeared to be in good health. We have no data on differential survival after fledging.

If spray was shut off and then turned on when the helicopters crossed the forest edge bordering on grassland openings of greater than 2 acres, the variability in DDT reaching ground level in these edges would likely be greater than at any other location. It should be recognized, then, that this study did not deal, precisely, with the potential effects on nestling survival of bluebirds and house wrens of a constant application rate of 0.75 lb DDT per acre. Rather, it measured the effects of such application subject to the spray shut off and release near the forest-grassland edge. These data should not be extrapolated to other species of insectivorous birds nor to other habitat types within the spray area. Further, this study treated only the short-term DDT effects on nestling survival.

In summary, we detected no detrimental short-term effects on nestling survival of mountain bluebirds and house wrens on study areas sprayed with 0.75 lb DDT per acre subject to spray shut off and release over forest-grassland edges adjacent to grassland areas greater than 2 acres in size.

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Appendix Tables

Appendix 1.--*Reproductive data for mountain bluebirds in the spray area*

Nest number	Eggs			Young		
	Number laid	Hatched	Failed	Died	Fledged	
		-Number- -Percent-	-Number- -Percent-	-Number- -Percent-	-Number- -Percent-	
1	6	6	0	0	6	100
2	6	5	1	0	5	100
3	4	4	0	0	4	100
4	5	5	0	0	5	100
5	5	5	0	0	5	100
6	5	5	0	0	5	100
7	5	5	0	0	5	100
8	6	6	0	0	6	100
9	5	5	0	0	5	100
10	6	6	0	0	6	100
11	5	5	0	0	5	100
12	5	4	1	0	4	100
Totals	63	61	2	0	61	100
$\bar{x}$	5.3	5.1	.2	0	5.1	
		96.8	3.2			

Appendix 2.--Reproductive data for mountain bluebirds in the nonspray area

Nest number	Eggs					Young			
	Number laid	Hatched		Failed		Died		Fledged	
	-Number-	-Percent-	-Number-	-Percent-		-Number-	-Percent-	-Number-	-Percent-
1	5	4	80	1	20	0	0	4	100
2	6	6	100	0	0	0	0	6	100
3	6	6	100	0	0	0	0	6	100
4	5	5	100	0	0	0	0	5	100
5	5	5	100	0	0	0	0	5	100
6	5	5	100	0	0	0	0	5	100
7	5	5	100	0	0	0	0	5	100
8	6	6	100	0	0	0	0	6	100
9	4	4	100	0	0	0	0	4	100
10	5	5	100	0	0	0	0	5	100
11	4	4	100	0	0	0	0	4	100
12	6	4	66	2	34	0	0	4	100
13	6	5	83	1	17	0	0	5	100
14	6	6	100	0	0	0	0	6	100
15	6	6	100	0	0	0	0	6	100
16	5	5	100	0	0	0	0	5	100
17	6	4	66	2	34	0	0	4	100
18	5	5	100	0	0	0	0	5	100
19	6	6	100	0	0	0	0	6	100
20	6	6	100	0	0	0	0	6	100
21	5	5	100	0	0	0	0	5	100
22	7	5	71	2	29	0	0	5	100
23	5	3	60	2	40	0	0	3	100
24	5	0	0	5	100	--	--	--	--
25	7	7	100	0	0	0	0	7	100
26	6	6	100	0	0	0	0	6	100
27	5	4	80	1	20	0	0	4	100
28	4	4	100	0	0	0	0	4	100
29	5	5	100	0	0	0	0	5	100
30	5	5	100	0	0	0	0	5	100
31	6	6	100	0	0	0	0	6	100
32	5	5	100	0	0	0	0	5	100
33	5	5	100	0	0	0	0	5	100
34	5	5	100	0	0	0	0	5	100
35	6	6	100	0	0	0	0	6	100
36	4	4	100	0	0	0	0	4	100
37	5	5	100	0	0	0	0	5	100
38	4	4	100	0	0	0	0	4	100
39	3	2	66	1	34	0	0	2	100
40	6	6	100	0	0	0	0	6	100
41	6	6	100	0	0	0	0	6	100
42	5	5	100	0	0	0	0	5	100
43	6	6	100	0	0	0	0	6	100
44	6	6	100	0	0	0	0	6	100
45	4	4	100	0	0	0	0	4	100
46	3	3	100	0	0	0	0	3	100
47	5	5	100	0	0	0	0	5	100
Totals	246	229	93.1	17	6.9	0	0	229	100
x	5.2	4.9		.4		0		4.9	100

Appendix 3. Reproduction data for house wrens in the area area

Nest number	Eggs			Young		
	Number laid	Hatched	Failed	Died		Fledged
		-Number- -Percent-	-Number- -Percent-	-Number- -Percent-	-Number- -Percent-	-Percent-
1	6	6	100	0	0	6
2	7	7	100	0	0	7
3	5	5	100	0	0	5
4	7	5	71.4	2	28.6	5
5	7	6	85.7	1	14.3	6
6	8	8	100	0	0	8
7	8	7	87.5	1	12.5	7
8	6	3	50.0	3	50.0	3
9	6	6	100.0	0	0	6
Totals	60	53	88.3	7	11.7	53
$\bar{x}$	6.7	5.9	.77	0	0	5.9

Appendix 4.--Reproductive data for house wrens in the nonspray area

Nest number	Eggs			Young		
	Number laid	Hatched	Failed	Died	Fledged	
		-Number- -Percent-	-Number- -Percent-	-Number- -Percent-	-Number- -Percent-	-Percent-
1	5	0	0	5	100	-- --
2	4	4	100	0	0	4 100
3	6	6	100	0	0	6 100
4	6	6	100	0	0	6 100
5	6	6	100	0	0	6 100
				6	100	0 0
Totals	27	22	81.5	5	18.5	6 27.3 16 72.7
	5.4	4.4	1.0	1.5	4.0	

Appendix 5.--*Reproductive data for Western bluebirds in the spray area*

Nest number	Eggs					Young			
	Number laid	Hatched		Failed		Died		Fledged	
		-Number-	-Percent-	-Number-	-Percent-	-Number-	-Percent-	-Number-	-Percent-
1	6	5	83.3	1	16.7	0	0	5	100

Appendix 6.--*Reproductive data for Western bluebirds in the nonspray area*

Nest number	Eggs					Young			
	Number laid	Hatched		Failed		Died		Fledged	
		-Number-	-Percent-	-Number-	-Percent-	-Number-	-Percent-	-Number-	-Percent-
1	5	5	100	0	0	0	0	5	100
2	5	5	100	0	0	0	0	5	100
3	5	5	100	0	0	0	0	5	100
4	3	3	100	0	0	0	0	3	100
5	4	4	100	0	0	0	0	4	100
6	6	6	100	0	0	0	0	6	100
7	5	5	100	0	0	0	0	5	100
8	6	6	100	0	0	0	0	6	100
9	5	5	100	0	0	0	0	5	100
Totals	44	44	100	0	0	0	0	44	100
̄	4.9	4.9		0		0		4.9	

Appendix 7.--Chronology of nesting activity — mountain bluebirds in spray areas

[illegible]

Nest number	Status
1	YF (6)
2	YF (5)
3	Y (4)
4	Y (5)
5	Y (5)
6	E (5)
7	Y (5)
8	YF (5)
9	
10	YF (6)
11	Y (5)
12	Y (4) E(1)
	YF (4) YF (5) YF (5) Y(4) E(1)
	Y(4) E(1)
	YF (4)

7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31/1 2 3 4 5 6 7 8 9

JULY (Cont.)

AUGUST

LEGEND

- ```
✓ = checked; no activity
E(1) = Eggs (number present)
Y(1) = Young (number present)
YF(1) = Young fledged (number fledged)
NB = Nest building
 = Best estimate of time from hatching to fledging
* = Date of spray application
```



Appendix 8.--Chronology of nesting activity -- mountain bluebirds in nonspray areas

| Nest number | Status |       |       |  |       |        |       |        |        |  |        |        |  |
|-------------|--------|-------|-------|--|-------|--------|-------|--------|--------|--|--------|--------|--|
| 1           |        |       | E (2) |  | E (5) |        |       |        |        |  |        |        |  |
| 2           | E (1)  |       | E (6) |  |       | Y (6)  |       |        | YF (6) |  |        |        |  |
| 3           | E (2)  |       | E (6) |  | Y (6) | Y (6)  |       |        | YF (6) |  |        |        |  |
| 4           | E (3)  |       | E (5) |  |       | Y (5)  |       | Y (5)  |        |  |        |        |  |
| 5           |        | E (4) |       |  | E (5) |        | Y (5) |        |        |  | Y (5)  | YF (5) |  |
| 6           |        |       |       |  |       |        |       |        |        |  |        | E (5)  |  |
| 7           |        | E (5) |       |  | Y (5) | Y (5)  |       |        |        |  | YF (5) |        |  |
| 8 and 9     |        | E (6) |       |  | Y (6) | Y (6)  |       |        |        |  | YF (6) | E (4)  |  |
| 10          |        | E (5) |       |  | Y (5) | YF (5) |       |        |        |  | E (3)  |        |  |
| 11          |        |       |       |  | Y (4) | Y (4)  |       |        |        |  | YF (4) |        |  |
| 12          |        | E (1) |       |  | E (6) |        | E (6) |        |        |  | Y (4)  | Y (4)  |  |
| 13          |        | E (6) |       |  | Y (6) |        |       | YF (5) |        |  | E (2)  | E (2)  |  |
| 14          |        | E (6) |       |  | E (1) |        |       | E (1)  |        |  |        |        |  |
| 15          |        | E (6) |       |  | Y (6) | Y (6)  |       |        |        |  |        | YF (6) |  |
| 16          |        | E (6) |       |  | Y (6) | YF (6) |       |        |        |  |        |        |  |
| 17          |        |       |       |  |       |        |       |        |        |  | E (4)  | E (5)  |  |
| 18          |        | E (6) |       |  |       |        |       | Y (4)  |        |  |        | YF (4) |  |
| 19          |        | E (5) |       |  |       |        |       | E (2)  |        |  |        | YF (5) |  |
| 20          |        | E (6) |       |  |       |        |       | Y (5)  |        |  |        |        |  |
| 21          |        | NB    |       |  |       |        |       | YF (6) |        |  |        |        |  |
| 22          |        | E (5) |       |  |       |        |       |        |        |  |        | E (6)  |  |
| 23          |        |       |       |  |       |        |       | Y (5)  |        |  |        | YF (5) |  |
| 24          |        | E (5) |       |  |       |        |       |        |        |  |        |        |  |
| 25          |        | E (7) |       |  |       |        |       |        |        |  |        |        |  |
| 26          |        | E (6) |       |  |       |        |       |        |        |  |        |        |  |
| 27          |        | E (5) |       |  |       |        |       |        |        |  |        |        |  |
| 28          |        | E (4) |       |  |       |        |       |        |        |  |        |        |  |
| 29          |        |       |       |  |       |        |       |        |        |  |        |        |  |
| 30          | NB     |       |       |  | E (5) |        | Y (5) |        |        |  |        |        |  |
| 31          |        |       |       |  |       |        |       |        |        |  |        |        |  |
| 32          | E (2)  |       |       |  | Y (5) |        | Y (5) |        |        |  |        |        |  |
| 33          |        |       |       |  |       |        |       |        |        |  |        |        |  |
| 34          | E (2)  |       |       |  | Y (5) |        | Y (5) |        |        |  |        |        |  |
| 35          |        |       |       |  | Y (6) |        |       |        |        |  | YF (6) |        |  |
| 36          |        |       |       |  | Y (4) |        |       |        |        |  | YF (4) |        |  |
| 37          |        |       |       |  |       |        |       | E (5)  |        |  |        | Y (5)  |  |
| 38          |        |       |       |  | Y (4) |        |       |        |        |  | YF (4) |        |  |
| 39          |        |       |       |  | NB    |        |       |        |        |  | Y (2)  |        |  |
| 40          |        |       |       |  | E (6) |        |       |        |        |  | E (1)  |        |  |
| 41          |        |       |       |  | E (6) |        |       |        |        |  | Y (6)  |        |  |
| 42          |        |       |       |  | E (5) |        |       |        |        |  | Y (6)  |        |  |
| 43          | E (6)  |       |       |  |       |        | Y (6) |        |        |  | YF (3) |        |  |
| 44          | E (5)  |       |       |  |       |        | E (6) |        |        |  | Y (2)  |        |  |
| 45          |        |       |       |  |       |        |       |        |        |  |        |        |  |
| 46          |        |       |       |  |       |        |       |        |        |  |        |        |  |
| 47          |        |       |       |  |       |        |       |        |        |  |        |        |  |

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30/ 1 2 3 4 5 6 7 8 9 10 11 12 13  
JUNE JULY

Appendix 8.--Chronology of nesting activity -- mountain bluebirds in area (Cont.)

Appendix 9.--Chronology of nesting activity — house wrens in spray areas

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- ✓ = checked; no activity
- E(1) = Eggs (number present)
- Y(1) = Young (number present)
- YF(1) = Young fledged (number fledged)
- NB = Nest building
- = Best estimate of time from hatching to fledging
- \* = Date of spray application

*Appendix 10.--Chronology of nesting activity — house wrens in nonspray areas*

| Nest number                                                                                               | Status |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Status       |      |
|-----------------------------------------------------------------------------------------------------------|--------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--------------|------|
| 1                                                                                                         |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | F<br>(5)     |      |
| 2                                                                                                         |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | YF<br>(4)    |      |
| 3                                                                                                         |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | E(3)<br>Y(3) |      |
| 4                                                                                                         |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Y<br>(6)     |      |
| 5                                                                                                         |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Y<br>(6)     |      |
| 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30/ 1 2 3 4 5 6 7 8 9 10 11 |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |              |      |
| JUNE                                                                                                      |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |              | JULY |

| Nest number                                                                                | Status |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |        |
|--------------------------------------------------------------------------------------------|--------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--------|
| 1                                                                                          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |        |
| 2                                                                                          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |        |
| 3                                                                                          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |        |
| 4                                                                                          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |        |
| 5                                                                                          |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |        |
| 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31/ 1 2 3 4 5 6 7 8 9 10 11 12 13 |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |        |
| JULY (Cont.)                                                                               |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | AUGUST |

LEGEND

- ✓ = checked; no activity
- E(1) = Eggs (number present)
- Y(1) = Young (number present)
- YF(1) = Young fledged (number fledged)
- NB = Nest building
- = Best estimate of time from hatching to fledging

*Appendix 11.--Chronology of nesting activity — Western bluebirds in the spray area*

| Nest number | Status |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|-------------|--------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
| 1           |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|             |        |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

LEGEND

- E(1) = Eggs (number present)
- Y(1) = Young (number present)
- YF(1) = Young fledged (number fledged)
- \*
- = Best estimate of time from hatching to fledging

Appendix 12.--Chronology of nesting activity -- Western bluebirds in the nonspray area

| Nest number | Status         |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
|-------------|----------------|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|
| 1           | E (5)          |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 2           | Y (5)          |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 3           | Y (5)          |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 4           | E (2)<br>Y (3) |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 5           | E (1)          |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 6           | YF (6)         |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 7           | E (2)<br>Y (3) |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 8           | Y (6)          |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 9           | YF (5)         |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |      |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |
| 1           | 2              | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19   | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| JUNE        |                |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    | JULY |    |    |    |    |    |    |    |    |    |    |    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |

| Nest number  | Status |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
|--------------|--------|---|---|---|---|---|---|---|----|----|----|----|--------|----|----|----|----|----|----|----|----|----|----|----|--|
| 1            | E (5)  |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 2            | YF (5) |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 3            | Y (5)  |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 4            | YF (5) |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 5            | E (4)  |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 6            | Y (4)  |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 7            | YF (5) |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 8            | YF (6) |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 9            |        |   |   |   |   |   |   |   |    |    |    |    |        |    |    |    |    |    |    |    |    |    |    |    |  |
| 1            | 2      | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14     | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |  |
| JULY (Cont.) |        |   |   |   |   |   |   |   |    |    |    |    | AUGUST |    |    |    |    |    |    |    |    |    |    |    |  |

LEGEND

- . = checked, no activity
- E(1) = Eggs (number present)
- Y(1) = Young (number present)
- YF(1) = Young fledged (number fledged)
- NB = Nest building
- = Best estimate of time from hatching to fledging



Appendix 13.--DDT spray (gal per acre)<sup>1/</sup> reaching ground level at each  
occupied nest box in the spray area -- mountain bluebirds

| Nest<br>number  | In<br>forest | At<br>box | In<br>open | Average |
|-----------------|--------------|-----------|------------|---------|
| 1 <sup>2/</sup> | 0            | --        | 0          | 0       |
| 2               | .340         | 0.340     | 1.500      | .726    |
| 3               | .030         | .075      | .300       | .135    |
| 4               | .150         | .150      | .300       | .200    |
| 5               | .112         | .450      | .300       | .287    |
| 6               | .075         | .060      | .300       | .145    |
| 7               | --           | .030      | .075       | .052    |
| 8               | .008         | .004      | .015       | .008    |
| 9               | .008         | .008      | .008       | .008    |
| 10              | .075         | .562      | 1.500      | .712    |
| 11              | .037         | .075      | .300       | .137    |
| 12              | .150         | .225      | .300       | .225    |
| Totals          | .985         | 1.979     | 4.898      | 2.635   |
| $\bar{x}$       | .090         | .180      | .408       | .220    |

<sup>1/</sup> DDT per acre = (gal per acre) (0.75 lb DDT per gal).

<sup>2/</sup> While this box, according to the spray cards, received no spray, it was included because it was surrounded by sprayed areas.

Appendix 14.--DDT spray (gal per acre)<sup>1/</sup> reaching ground level at each  
occupied nest box in the spray area -- house wrens

| Nest<br>number | In<br>forest | At<br>box | In<br>open | Average |
|----------------|--------------|-----------|------------|---------|
| 1              | --           | 0.260     | 0.300      | 0.280   |
| 2              | 0.008        | .008      | --         | .008    |
| 3              | 0            | .008      | .052       | .020    |
| 4              | .075         | .008      | .015       | .033    |
| 5              | .150         | .015      | .300       | .155    |
| 6              | .075         | 0         | 0          | .025    |
| 7 & 8          | .082         | .015      | .045       | .047    |
| 9              | .008         | .300      | .026       | .111    |
| Totals         | .398         | .614      | .738       | .679    |
| $\bar{x}$      | .057         | .076      | .105       | .085    |

<sup>1/</sup> DDT per acre = (gal per acre) (0.75 lb DDT per gal).

Appendix 15.--DDT spray (gal per acre)<sup>1/</sup> reaching ground level in each  
study location

| Cluster          | In forest |           |       | At box |           |       | In open |           |       |
|------------------|-----------|-----------|-------|--------|-----------|-------|---------|-----------|-------|
|                  | N         | $\bar{x}$ | S.D.  | N      | $\bar{x}$ | S.D.  | N       | $\bar{x}$ | S.D.  |
| Powatka Ridge    | 40        | 0.150     | 0.108 | 41     | 0.106     | 0.032 | 41      | 0.182     | 0.043 |
| McAllister Ridge | 33        | .074      | .063  | 37     | .086      | .075  | 26      | .278      | .217  |
| Horseshoe Ridge  | 58        | .077      | .011  | 58     | .084      | .014  | 57      | .097      | .017  |
| McAllister       | 41        | .061      | .057  | 44     | .114      | .098  | 48      | .325      | .219  |

<sup>1/</sup> DDT per acre = (gal per acre) (0.75 lb DDT per acre).

Appendix 16.--Rate of capture (mg per day ) of insects in malaise traps--spray areas<sup>1/</sup> vs. nonspray areas<sup>1/</sup>

| Day number <sup>2/</sup> |             | 15  | 16  | 17  | 18  | 19 | 20 | 21 | 22 | 23  | 24 | 25 | 26  | 27  | 28 | 29 | 30 | 31 | 1  | 2   | 3   |    |
|--------------------------|-------------|-----|-----|-----|-----|----|----|----|----|-----|----|----|-----|-----|----|----|----|----|----|-----|-----|----|
| Area                     | Trap number | 15  | 16  | 17  | 18  | 19 | 20 | 21 | 22 | 23  | 24 | 25 | 26  | 27  | 28 | 29 | 30 | 1  | 2  | 3   |     |    |
| June                     |             |     |     |     |     |    |    |    |    |     |    |    |     |     |    |    |    |    |    |     |     |    |
| spray                    | 1           | 472 | --  | --  | 375 | -- | -- | -- | -- | 253 | -- | -- | --  | --  | 37 | -- | -- | -- | -- | --  |     |    |
|                          | 2           | 119 | --  | --  | 76  | -- | -- | -- | -- | 54  | -- | -- | --  | --  | 4  | -- | -- | -- | -- | --  |     |    |
|                          | 3           | 569 | --  | --  | 461 | -- | -- | -- | -- | 314 | -- | -- | --  | --  | 52 | -- | -- | -- | -- | 13  |     |    |
|                          | 4           | 608 | --  | --  | 232 | -- | -- | -- | -- | --  | -- | -- | --  | --  | 28 | -- | -- | -- | -- | 30  |     |    |
|                          | 5           | --  | --  | 405 | --  | -- | -- | -- | -- | --  | -- | -- | 123 | --  | -- | -- | -- | -- | -- | --  |     |    |
|                          | 6           | --  | --  | 151 | --  | -- | -- | -- | 87 | --  | -- | -- | --  | --  | 5  | -- | -- | -- | -- | --  |     |    |
|                          | 7           | --  | 35  | --  | --  | -- | -- | -- | 13 | --  | -- | -- | --  | --  | 8  | -- | -- | -- | -- | --  |     |    |
| nonspray                 | 1           | 120 | --  | --  | 65  | -- | -- | -- | -- | 75  | -- | -- | --  | --  | 51 | -- | -- | -- | -- | --  |     |    |
|                          | 2           | --  | --  | 302 | --  | -- | -- | -- | -- | --  | -- | -- | --  | 153 | -- | -- | -- | -- | -- | --  |     |    |
|                          | 3           | 186 | --  | --  | 231 | -- | -- | -- | -- | 207 | -- | -- | --  | --  | 82 | -- | -- | -- | -- | --  |     |    |
|                          | 4           | 195 | --  | --  | 262 | -- | -- | -- | -- | 40  | -- | -- | --  | --  | 48 | -- | -- | -- | -- | --  |     |    |
|                          | 5           | --  | 29  | --  | --  | -- | -- | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  |     |    |
|                          | 6           | --  | 137 | --  | --  | -- | -- | -- | -- | 50  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  |     |    |
| July                     |             |     |     |     |     |    |    |    |    |     |    |    |     |     |    |    |    |    |    |     |     |    |
| Day number <sup>2/</sup> |             | 34  | 35  | 36  | 37  | 38 | 39 | 40 | 41 | 42  | 43 | 44 | 45  | 46  | 47 | 48 | 49 | 50 | 51 | 52  | 53  | 54 |
| Area                     | Trap number | 4   | 5   | 6   | 7   | 8  | 9  | 10 | 11 | 12  | 13 | 14 | 15  | 16  | 17 | 18 | 19 | 20 | 21 | 22  | 23  | 24 |
| July (Cont.)             |             |     |     |     |     |    |    |    |    |     |    |    |     |     |    |    |    |    |    |     |     |    |
| spray                    | 1           | --  | --  | --  | --  | -- | 37 | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | 159 | --  |    |
|                          | 2           | --  | --  | --  | --  | -- | -- | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |
|                          | 3           | --  | --  | --  | --  | -- | -- | -- | -- | 23  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |
|                          | 4           | --  | --  | --  | --  | -- | -- | -- | -- | 19  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |
|                          | 5           | --  | 15  | --  | --  | -- | -- | -- | -- | --  | -- | -- | 16  | --  | -- | -- | -- | -- | -- | --  | 89  |    |
|                          | 6           | --  | --  | --  | --  | -- | -- | 8  | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |
|                          | 7           | --  | --  | --  | --  | -- | -- | 8  | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |
| nonspray                 | 1           | --  | --  | --  | --  | -- | 41 | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |
|                          | 2           | --  | 87  | --  | --  | -- | -- | -- | -- | --  | -- | -- | 66  | --  | -- | -- | -- | -- | -- | --  | 178 |    |
|                          | 3           | --  | --  | --  | --  | -- | -- | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | 176 | --  |    |
|                          | 4           | --  | --  | --  | --  | -- | -- | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | 36  | --  |    |
|                          | 5           | --  | --  | --  | --  | 75 | -- | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |
|                          | 6           | --  | --  | --  | --  | 27 | -- | -- | -- | --  | -- | -- | --  | --  | -- | -- | -- | -- | -- | --  | --  |    |

<sup>1/</sup> Data presented here correspond to the data points in figure 1.

<sup>2/</sup> Day numbers correspond to standard day numbers for all appendices.

## Acknowledgments

The paper was critically reviewed by Howard Wight (Cooperative Wildlife Resource Unit, Oregon State University), Steven Herman (Evergreen State College), Lynn Frandsen (Environmental Protection Agency), Glen Hetzel, Rod Canutt, Rod Miller, and Gerald Strickler (USDA Forest Service). Their efforts aided us materially. Interpretation and remaining errors are our responsibility.

Rod Canutt, overall monitoring coordinator for the spray project, was instrumental in initiation of this research and made valuable suggestions in terms of research design. Dr. Richard Mason provided the data on insect response to DDT spray. Britt Ward Thomas, a Forest Service volunteer, made material contribution to the project.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife -- if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.



*Use Pesticides Safely*  
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U.S. DEPARTMENT OF AGRICULTURE





Thomas, Jack Ward, and D. Calvin McCluskey

1974. Effects of aerial application of DDT for tussock moth control on nestling survival of mountain bluebirds and house wrens. USDA For. Serv. Res. Pap. PNW-185, 37 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

DDT application at 0.75 lb/acre had no discernible short-term ill effect on mountain bluebird (*Sialia currucoides*) and house wren (*Troglodytes aedon*) nestling survival.

Keywords: DDT monitoring, bluebirds, house wrens, bird reproduction effects.

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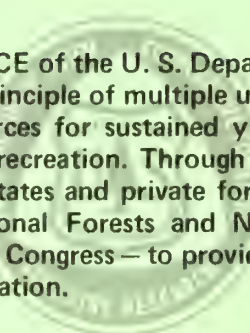
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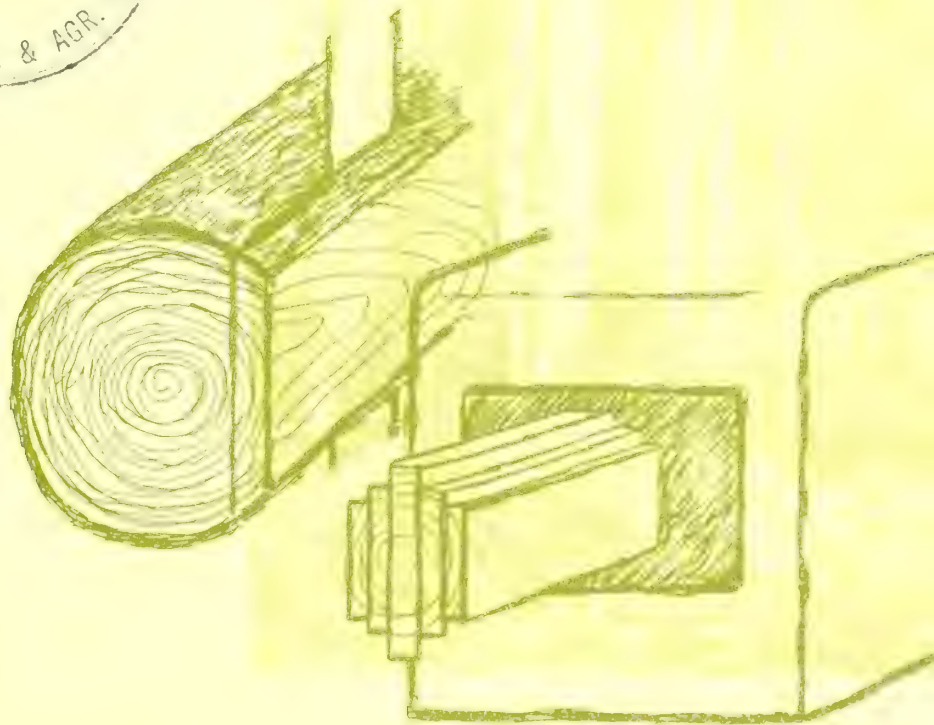
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# LUMBER RECOVERY from GRAND FIR THINNINGS at a BANDMILL and SHIPPING CENTER



THOMAS D. FAHEY  
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## Abstract

Trees cut in thinning of a grand fir stand were processed in a bandmill and a Chip-N-Saw facility. Lumber grades produced were similar at each mill. The Chip-N-Saw as operated here produced considerably less lumber and sawdust and substantially more chips per unit of log measure.

Keywords: Lumber recovery studies, grand fir, thinnings.

## Summary and Conclusions

Grand fir thinnings processed at a bandmill and a Chip-N-Saw produced 89 and 83 percent, respectively, of total lumber in Standard and Better grades.

The bandmill produced more lumber, more sawdust, and considerably less chips than the Chip-N-Saw per unit of log volume.

Overruns, based on uniform Bureau scaling methods and volumes, and surfaced dry lumber were 63 percent for the bandmill and 29 percent for the Chip-N-Saw. Of this 34-percent difference, 27 percent can be attributed to mill operations and 7 percent to log diameter distribution.

The difference in overruns between the mills has little relation to lumber sizes. Of the 27 percent attributed to differences in the milling process, not more than 3 percent can be explained in terms of volumes of 1-inch boards. Apparently the operation of the mills influenced the recovery of 2-inch dimension items also.

The proportion of lumber grades and items was quite similar at both mills. Differences probably resulted from drying and planing practice. The rough green lumber grades were slightly higher at the Chip-N-Saw than at the bandmill, but grades were slightly lower in the surfaced dry condition.

Log cubic volume proved a much better predictor of lumber recovery than Scribner scale. At either mill, the coefficients of variation were as follows:

|                                                                      | <u>Bandmill</u>                    | <u>Chip-N-Saw</u> |
|----------------------------------------------------------------------|------------------------------------|-------------------|
|                                                                      | <i>- - - - - Percent - - - - -</i> |                   |
| Recovery ratio (board-foot lumber<br>tally/net log scale--Scribner)  | 27.6                               | 35.5              |
| Lumber recovery factor (board-foot<br>lumber tally/log cubic volume) | 20.7                               | 21.1              |

At the time the study logs were processed, the prices per thousand board feet of lumber were approximately: Standard and Better--\$75, Utility--\$40, and Economy--\$20. The chip price was approximately \$18 per oven-dry ton. The relatively low lumber price and stable chip price in effect at the time may have affected the products produced at the Chip-N-Saw.

## Summary of Recovery by Mill<sup>1/</sup>

| <u>Characteristic</u>                             | <u>Bandmill</u> | <u>Chip-N-Saw</u>   |
|---------------------------------------------------|-----------------|---------------------|
| Mean log scaling diameter, inches                 | 6.9             | 6.5                 |
| Diameter range, inches                            | 4-14            | 4-12                |
| Scaling defect, percent                           | 3               | 4                   |
| Standard & Better lumber, percent                 | 89              | 83                  |
| Utility and No. 3 lumber, percent                 | 9               | 14                  |
| Economy lumber, percent                           | 2               | 3                   |
| Percent overrun (surfaced dry)                    | 63 (59)         | 29 (32)             |
| Percent log cubic volume in<br>rough green lumber | 54.4 (53.6)     | 48.1 (49.9)         |
| Total chip recovery, dry tons                     | 22.40           | <sup>2/</sup> 28.16 |
| Dry tons of chips/M net log scale                 | .91             | 1.38                |
| Dry tons of chips/M cubic feet                    | 4.07            | 6.00                |

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<sup>1/</sup> Figures in parentheses are developed from regression and covariance analysis to eliminate the differences due to unequal log diameter distributions at the two mills.

<sup>2/</sup> Does not include chips developed in board trimming or resawing of less than 1 dry ton.

## Introduction

Commercial thinning sales are producing an increasing part of the total timber harvest in the Pacific Northwest. Grand fir *Abies grandis* (Dougl.) Lindl.) is one of the most common of the species that grow in association with either Douglas-fir or ponderosa pine. As lumber, it is usually combined with white, noble, and Pacific silver firs and western hemlock and marketed as hem-fir.

In 1970 the Forest Service and the Bureau of Land Management cooperated with the forest products industry to conduct a lumber recovery study on logs from a commercial thinning timber sale. They were processed in April 1970 through a bandmill and a 12-inch capacity Chip-N-Saw with a 4-inch center cant and a double arbor circular saw for cant breakdown.<sup>3/</sup> The details of study methods and mill equipment are in the Study Procedures section at the end of this paper.

The information on lumber and chip recovery will be useful to mill operators and timber managers in predicting product yields from similar stands, and evaluating different production methods.

## Results

The study results are presented in a series of tables and in figures designed to illustrate the relative differences in recovery between the two mills.

The tables are arranged to allow the user to apply product prices. The lumber from the two mills was quite similar in grade and item. Only the ratio of chips to lumber and fluctuations in chip and lumber prices would result in any pronounced variation in product values.

Example, using figures from the summary and prices of \$140 per thousand board feet for Standard and Better, \$110 for Utility, \$60 for Economy, and \$25 per ton of chips:

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<sup>3/</sup> Mention of companies or products does not constitute endorsement by the U.S. Department of Agriculture.



|                                 | <u>Bandmill</u> |              |              | <u>Chip-N-Saw</u> |              |              |
|---------------------------------|-----------------|--------------|--------------|-------------------|--------------|--------------|
|                                 | <u>Percent</u>  | <u>Price</u> | <u>Value</u> | <u>Percent</u>    | <u>Price</u> | <u>Value</u> |
| Standard & Better               | 89              | x \$140      | = \$124.60   | 83                | x \$140      | = \$116.20   |
| Utility                         | 9               | x 110        | = 9.90       | 14                | x 110        | = 15.40      |
| Economy                         | 2               | x 60         | = 1.20       | 3                 | x 60         | = 1.80       |
| Value/M lumber tally            |                 |              | \$135.70     |                   |              | \$133.40     |
| Lumber value/M net<br>log scale | $\frac{4}{159}$ | x 135.70     | = \$215.76   | $\frac{4}{132}$   | x 133.40     | = \$176.09   |
|                                 |                 |              |              |                   |              |              |
|                                 | <u>Tons/M</u>   | <u>Price</u> | <u>Value</u> | <u>Tons/M</u>     | <u>Price</u> | <u>Value</u> |
| Chip value/M net<br>log scale   | 0.91            | x \$25       | = \$22.75    | 1.38              | x \$25       | = \$34.50    |
| Total value/M net<br>log scale  |                 |              | \$238.51     |                   |              | \$210.59     |

## RECOVERY RATIO (OVERRUN)

The most commonly used recovery ratio is board feet lumber tally per board foot of net log scale expressed as a percent. It is equal to "overrun" plus 100 percent. The recovery ratio of surfaced dry lumber averaged 163 percent for bandmill and 129 percent for the Chip-N-Saw (table 1). Adjustment<sup>5/</sup> for different log diameter distributions brings the recoveries to 159 percent for the bandmill and 132 percent for the Chip-N-Saw. The largest differences were in the 6- and 7-inch scaling diameter logs. We believe this was caused by the Chip-N-Saw operator's inability to estimate the log diameter and select the proper machine setting for small logs. His view of logs was obscured by the enclosed infeed chain. Figure 1 shows the general relationship of the recovery ratios at the two mills.

The low recovery reported at the Chip-N-Saw, particularly on 6- and 7-inch logs, led the cooperator to install log diameter sensing equipment. Studies completed since then on Chip-N-Saws with diameter sensors show considerably higher overruns with logs of the same diameter range.

<sup>4/</sup> 100 + overrun.

<sup>5/</sup> See footnote 1.

Table 1.--Lumber recovery per unit net log scale by mill for surfaced dry lumber

| Scaling<br>diameter<br>(inches) | Scribner |     | Lumber<br>tally | Recovery<br>ratio |
|---------------------------------|----------|-----|-----------------|-------------------|
|                                 | Gross    | Net |                 |                   |

----- Board feet -----

Bandmill:

|          |        |        |        |     |
|----------|--------|--------|--------|-----|
| 4        | 690    | 690    | 1,333  | 193 |
| 5        | 4,590  | 4,590  | 6,941  | 151 |
| 6        | 2,580  | 2,480  | 3,671  | 148 |
| 7        | 3,480  | 3,400  | 5,388  | 158 |
| 8        | 4,010  | 3,850  | 6,619  | 172 |
| 9        | 3,840  | 3,680  | 6,472  | 176 |
| 10       | 2,910  | 2,830  | 4,417  | 156 |
| 11       | 1,040  | 1,030  | 1,664  | 162 |
| 12       | 1,230  | 1,180  | 2,075  | 176 |
| 13       | 650    | 640    | 1,014  | 158 |
| 14       | 230    | 190    | 301    | 158 |
| All logs | 25,250 | 24,510 | 39,895 | 163 |

Chip-N-Saw:

|          |        |        |        |     |
|----------|--------|--------|--------|-----|
| 4        | 100    | 100    | 187    | 187 |
| 5        | 5,150  | 5,070  | 6,671  | 132 |
| 6        | 4,690  | 4,470  | 4,918  | 110 |
| 7        | 3,100  | 2,920  | 3,472  | 119 |
| 8        | 3,230  | 3,130  | 4,282  | 137 |
| 9        | 1,750  | 1,660  | 2,407  | 145 |
| 10       | 2,300  | 2,230  | 3,125  | 140 |
| 11       | 420    | 390    | 567    | 145 |
| 12       | 460    | 460    | 655    | 142 |
| All logs | 21,200 | 20,430 | 26,284 | 129 |

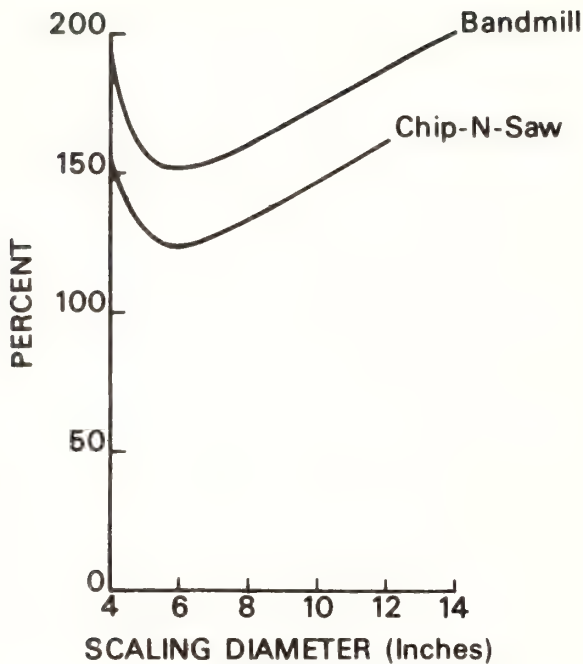


Figure 1.--Recovery ratio, board feet of lumber tally (surfaced dry) per board foot of net log scale.

## LUMBER RECOVERY FACTOR

Lumber recovery factor is board feet of rough green lumber tally per cubic foot of gross log volume (table 2). The recovery factor for the bandmill averaged 7.51 board feet per cubic foot of log, while the recovery factor at the Chip-N-Saw was 5.92 board feet. When the diameters were adjusted to equalize scaling diameter distributions, the ratios were 7.29 at the bandmill and 6.22 at the Chip-N-Saw. Figure 2 shows the general trend of recovery factors for the two systems. As with recovery ratios, the big differences were in the 6- and 7-inch logs.

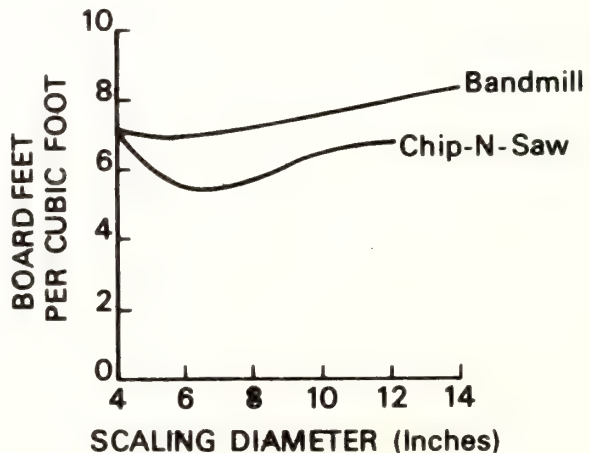


Figure 2.--Recovery factors, board feet of lumber (rough green) per cubic foot of log volume.

Table 2.--Recovery of rough green lumber, sawdust, and chippable volume

| Scaling diameter (inches) | Total rough green lumber recovery | Gross volume of logs | Recovery factor | Lumber volume | Sawdust volume        | Chippable volume |                       |
|---------------------------|-----------------------------------|----------------------|-----------------|---------------|-----------------------|------------------|-----------------------|
|                           | Board feet                        | Cubic feet           |                 | Cubic feet    | Percent <sup>1/</sup> | Cubic feet       | Percent <sup>1/</sup> |
| Bandmill:                 |                                   |                      |                 |               |                       |                  |                       |
| 4                         | 1,387                             | 183.93               | 7.54            | 103.89        | 56.5                  | 22.49            | 12.2                  |
| 5                         | 7,189                             | 1,017.00             | 7.07            | 535.75        | 52.7                  | 115.98           | 11.4                  |
| 6                         | 3,807                             | 544.07               | 7.00            | 279.84        | 51.4                  | 59.46            | 10.9                  |
| 7                         | 5,591                             | 721.47               | 7.75            | 405.46        | 56.2                  | 83.94            | 11.6                  |
| 8                         | 6,865                             | 938.77               | 7.31            | 495.74        | 52.3                  | 100.48           | 10.7                  |
| 9                         | 6,676                             | 858.83               | 7.77            | 487.43        | 56.8                  | 95.99            | 11.2                  |
| 10                        | 4,562                             | 577.18               | 7.90            | 335.51        | 58.1                  | 64.14            | 11.1                  |
| 11                        | 1,723                             | 231.16               | 7.45            | 126.05        | 54.5                  | 23.33            | 10.1                  |
| 12                        | 2,140                             | 259.01               | 8.26            | 150.14        | 58.0                  | 27.79            | 10.7                  |
| 13                        | 1,051                             | 126.60               | 8.30            | 74.82         | 59.1                  | 13.70            | 10.8                  |
| 14                        | 309                               | 42.06                | 7.35            | 22.74         | 54.1                  | 4.15             | 9.9                   |
| All logs                  | 41,300                            | 5,542.14             | 7.51            | 2,994.63      | 54.9                  | 611.45           | 11.1                  |
|                           |                                   |                      |                 |               |                       | 1,871.26         | 34.0                  |
| Chip-N-Saw:               |                                   |                      |                 |               |                       |                  |                       |
| 4                         | 195                               | 6.09                 | 32.01           | 15.55         | 48.6                  | 1.68             | 5.2                   |
| 5                         | 7,035                             | 6.27                 | 1,121.48        | 561.59        | 50.1                  | 62.01            | 5.5                   |
| 6                         | 5,207                             | 5.94                 | 875.84          | 417.95        | 47.7                  | 45.88            | 5.2                   |
| 7                         | 3,673                             | 4.30                 | 854.83          | 297.21        | 34.8                  | 33.32            | 3.2                   |
| 8                         | 4,533                             | 6.26                 | 754.35          | 368.79        | 46.9                  | 39.42            | 5.4                   |
| 9                         | 2,546                             | 6.57                 | 387.37          | 207.68        | 53.6                  | 20.37            | 5.2                   |
| 10                        | 3,327                             | 7.01                 | 474.73          | 271.87        | 52.3                  | 26.21            | 5.5                   |
| 11                        | 591                               | 6.98                 | 84.66           | 48.41         | 57.2                  | 4.70             | 5.6                   |
| 12                        | 697                               | 6.51                 | 107.06          | 56.68         | 52.9                  | 5.38             | 5.0                   |
| All logs                  | 27,804                            | 5.93                 | 4,692.33        | 2,245.73      | 47.9                  | 238.97           | 5.1                   |
|                           |                                   |                      |                 |               |                       | 2,207.63         | 47.0                  |

<sup>1/</sup> Percent of log volume.

## CUBIC RECOVERY PERCENT

The cubic recovery of actual rough green lumber and the calculated wood volume converted to sawdust and chippable volumes are listed in table 2 by scaling diameter and for all logs. Figure 3 shows the percent of log volume in products and the individual relationships to diameter. Adjusted to eliminate differences due to scaling diameter distributions, the recovery percents are as follows:

|                                      | <u>Bandmill</u> | <u>Chip-N-Saw</u> | <u>Difference</u> |
|--------------------------------------|-----------------|-------------------|-------------------|
|                                      | <i>Percent</i>  |                   |                   |
| Surfaced dry lumber                  | 42.9            | 36.5              | 6.4               |
| Shrinkage, planer shavings, and trim | <u>10.7</u>     | <u>13.4</u>       | <u>2.7</u>        |
| Rough green lumber                   | <u>53.6</u>     | <u>49.9</u>       | <u>3.7</u>        |
| Sawdust                              | 11.3            | 5.4               | 5.9               |
| Chippable volume                     | 35.1            | 44.7              | 9.6               |

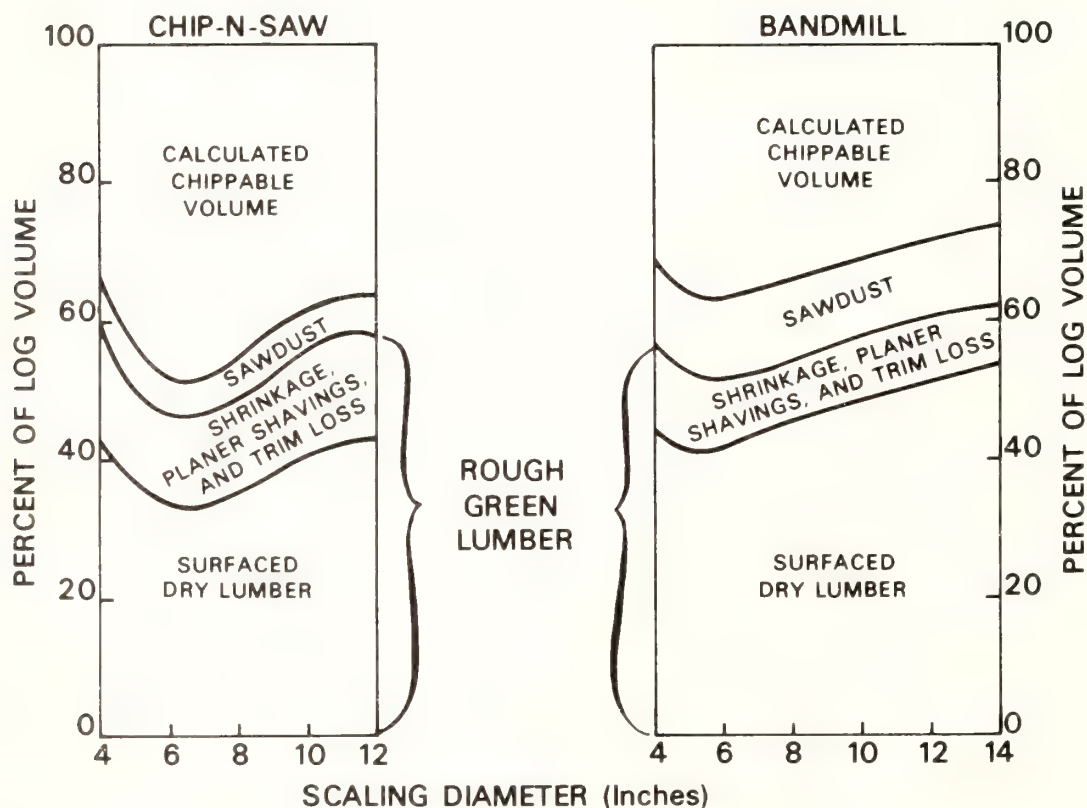


Figure 3.--Cumulative percentages of lumber, sawdust, and chippable volume.



The lumber processed at the Chip-N-Saw lost 2.7 percent more of the log cubic volume from rough green to surfaced dry tally than the bandmill. Of this loss, 2.6 percent can be attributed to larger rough green dimensions of the boards from the Chip-N-Saw, the other 0.1 percent being due to planer trimming. The Chip-N-Saw was apparently producing larger rough green lumber than necessary for finished sizes. The 1-inch green lumber at both mills was the same thickness. The net thickness of the 2-inch green lumber at the Chip-N-Saw was 1-29/32 inch, while the 2-inch green lumber at the bandmill was 1-24/32 inch thick. The widths were similar at both mills. The above tabulation shows that more of difference in chippable volume comes from differences in sawdust volume than differences in rough green lumber volume.

### CHIP RECOVERY

The calculated chippable volume is the portion of total log cubic volume available for chipping, not actual chip volume recovery.

The calculated volume available for chipping was 1,871.26 cubic feet at the bandmill and 2,207.63 cubic feet at the Chip-N-Saw. The dry chips recorded on the study shipment invoices were 22.40 tons at the bandmill and 28.16 tons at the Chip-N-Saw.

The calculated chippable volume converts to 23.9 pounds per cubic foot for the bandmill and 25.5 pounds per cubic foot for the Chip-N-Saw.

The generally accepted weight for grand fir is 23 pounds per cubic foot<sup>6/</sup> based on green volume and oven-dry weight. With allowance for screening loss and some chippable material hogged at the bandmill, the actual chippable volume was considerably higher than the calculated chippable volume. This is due in part to using nominal rather than actual log lengths but primarily to dropping fractional inches in scaling by Scaling Bureau rules.<sup>7/</sup>

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<sup>6/</sup> USDA Forest Service, Forest Products Laboratory. Wood Handbook No. 72, 527 p. U.S. Government Printing Office, Washington, D.C., 1955.

<sup>7/</sup> David Bruce and Donald J. DeMars. Effect on diameter estimates of rounding rules in scaling. USDA Forest Service Research Note PNW-226, 8 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1974.

## LUMBER GRADE RECOVERY

The recoveries by lumber grade are similar to other studies<sup>8/</sup> for small sound logs. The lumber recovery by grade and item is listed in table 3. The comparative percents by mill for surfaced dry lumber are as follows:

|            | <u>Standard &amp; Better</u> | <u>Utility</u> | <u>Economy</u> |
|------------|------------------------------|----------------|----------------|
| Bandmill   | 89                           | 9              | 2              |
| Chip-N-Saw | 83                           | 14             | 3              |

Any difference in lumber grades appears due to either grading or dry kiln and planing differences. A higher percentage of rough green Standard and Better was produced by the Chip-N-Saw than by the bandmill.

*Table 3.--Percent of total production by grade and dimension by mill*

| Scaling<br>dimension<br>(inches) | Select<br>structural | Construction<br>no. 1 | Standard<br>no. 2 | Utility<br>and no. 3 | Economy | Total                |
|----------------------------------|----------------------|-----------------------|-------------------|----------------------|---------|----------------------|
| ----- Percent -----              |                      |                       |                   |                      |         |                      |
| Bandmill:                        |                      |                       |                   |                      |         |                      |
| 1 x 4                            | 2.71                 | 3.41                  | 1.74              | 0.79                 | 0.09    | 8.74                 |
| 1 x 6                            | .16                  | .22                   | .14               | .06                  | .01     | .58                  |
| 2 x 4                            | 7.42                 | 9.85                  | 5.10              | 2.32                 | .41     | 25.09                |
| 2 x 6                            | 10.10                | 14.48                 | 7.80              | 3.67                 | .62     | 36.67                |
| 2 x 8                            | 6.35                 | 8.28                  | 4.14              | 1.82                 | .32     | 20.92                |
| 2 x 10<br>and wider              | 2.59                 | 3.21                  | 1.53              | .58                  | .08     | 8.00                 |
| Total                            | 29.32                | 39.46                 | 20.45             | 9.24                 | 1.53    | <sup>1/</sup> 100.00 |
| Chip-N-Saw:                      |                      |                       |                   |                      |         |                      |
| 1 x 4                            | 2.20                 | 2.98                  | 1.15              | .84                  | .17     | 7.34                 |
| 1 x 6                            | .10                  | .38                   | .20               | .41                  | .14     | 1.24                 |
| 2 x 4                            | 6.74                 | 15.74                 | 6.21              | 4.60                 | 1.05    | 34.35                |
| 2 x 6                            | 7.06                 | 14.43                 | 5.71              | 4.97                 | 1.24    | 33.42                |
| 2 x 8                            | 3.28                 | 8.16                  | 3.28              | 2.47                 | .51     | 17.70                |
| 2 x 10<br>and wider              | .99                  | 3.12                  | 1.18              | .60                  | .06     | 5.95                 |
| Total                            | 20.39                | 44.81                 | 17.74             | 13.89                | 3.17    | <sup>1/</sup> 100.00 |

<sup>1/</sup> Cross totals may not add due to rounding.

<sup>8/</sup> J. Dobie and C. F. McBride. Lumber recovery from second-growth Douglas-fir in British Columbia. Forest Products Journal 14: 55-60. 1964. Also see Thomas D. Fahey and Donald C. Martin. Lumber recovery from second-growth Douglas-fir. USDA Forest Service Research Paper PNW-177, 20 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1974.

One-inch lumber comprised 9.3 and 8.6 percent of the total lumber volume at the bandmill and Chip-N-Saw, respectively. This accounted for 15.2 and 11.1 percent of the overrun. Therefore, no more than 3.1 percent of the difference in study overrun can be accounted for by differences in recovery of 1-inch lumber.

Lumber grade did not vary appreciably by log scaling diameter (table 4). This was also true in the rough green lumber grades before conversion to surfaced dry grades.

*Table 4.--Lumber grade recovery as a percent of lumber tally volume and number of logs by diameter class and mill*

| Scaling<br>diameter<br>(inches) | Number<br>of logs | Select<br>structural | Construction<br>no. 1 | Standard<br>no. 2 | Utility<br>and no. 3 | Economy |
|---------------------------------|-------------------|----------------------|-----------------------|-------------------|----------------------|---------|
| ----- Percent -----             |                   |                      |                       |                   |                      |         |
| Bandmill:                       |                   |                      |                       |                   |                      |         |
| 4                               | 38                | 29.03                | 39.16                 | 20.86             | 9.45                 | 1.50    |
| 5                               | 157               | 28.92                | 39.29                 | 20.54             | 9.72                 | 1.53    |
| 6                               | 57                | 29.47                | 38.95                 | 20.22             | 9.64                 | 1.72    |
| 7                               | 64                | 25.98                | 39.07                 | 22.10             | 10.82                | 2.03    |
| 8                               | 61                | 29.11                | 39.70                 | 20.56             | 9.14                 | 1.49    |
| 9                               | 41                | 29.96                | 39.97                 | 20.10             | 8.56                 | 1.41    |
| 10                              | 24                | 30.47                | 39.26                 | 19.76             | 8.90                 | 1.61    |
| 11                              | 7                 | 29.15                | 39.12                 | 20.79             | 9.44                 | 1.50    |
| 12                              | 8                 | 32.24                | 40.34                 | 19.33             | 7.37                 | .72     |
| 13                              | 4                 | 33.53                | 39.45                 | 18.34             | 7.50                 | 1.18    |
| 14                              | 1                 | 37.87                | 40.53                 | 16.61             | 4.65                 | .34     |
| All logs                        | 462               | 29.32                | 39.46                 | 20.44             | 9.25                 | 1.53    |
| Chip-N-Saw:                     |                   |                      |                       |                   |                      |         |
| 4                               | 5                 | 11.76                | 48.66                 | 19.79             | 16.05                | 3.74    |
| 5                               | 171               | 19.50                | 44.36                 | 18.40             | 14.35                | 3.39    |
| 6                               | 92                | 20.29                | 46.18                 | 17.67             | 13.03                | 2.83    |
| 7                               | 56                | 20.82                | 45.48                 | 17.02             | 13.59                | 3.09    |
| 8                               | 48                | 22.09                | 44.23                 | 17.56             | 13.17                | 2.95    |
| 9                               | 20                | 19.24                | 42.46                 | 17.95             | 16.33                | 4.02    |
| 10                              | 18                | 21.22                | 44.70                 | 16.99             | 13.99                | 3.10    |
| 11                              | 4                 | 21.16                | 48.50                 | 16.23             | 11.29                | 2.82    |
| 12                              | 3                 | 18.63                | 44.43                 | 20.14             | 14.20                | 2.60    |
| All logs                        | 419               | 20.39                | 44.81                 | 17.74             | 13.89                | 3.17    |

# Study Procedures

## TIMBER SAMPLE AREAS

The study trees were taken from two timber sales in one 65-year-old stand on site class IV in the Hood River District of the Mount Hood National Forest in Oregon. The stand basal area per acre was 110 square feet of grand fir and 30 square feet of Douglas-fir. Basal area cut was 35 square feet of grand fir and 1 square foot of Douglas-fir per acre. None of the Douglas-fir cut was processed during the study.

Trees were selected by the District timber sale crew to salvage existing or anticipated mortality but primarily to improve growing conditions and spacing for the residual trees.

Equipment at the bandmill did not limit log size; therefore some larger trees were included than in the Chip-N-Saw sample (table 5).

## LOG SCALING AND GRADING

The woods-length logs were scaled and graded in the millyard by a U.S. Forest Service check scaler. Scaling was according to uniform Bureau rules for west side,<sup>9/</sup> with logs up to 40 feet in length being scaled as one piece. Logs were graded according to the rules for hemlock, silver, and white fir when grading logs in the standing tree.<sup>10/</sup> Defects not visible nor indicated on the log surface were not considered in grading.

## CUBIC MEASUREMENTS

Cubic volume computations are based on the scaling length and end diameter measurements of the woods-length logs. Butt log large end diameters are measured on a projected conic section and exclude stump flare. Log cubic volume is computed by the formula

$$V = \frac{\pi (D_s^2 + D_s D_l + D_l^2) \times L}{3 \times 4 \times 144}$$

where  $\pi = 3.1416$

$D_s$  = small end diameter in inches

$D_l$  = large end diameter in inches

$L$  = nominal length in feet

No deductions were made from log gross cubic volume.

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<sup>9/</sup> Official Log Scaling and Grading Rules (July 1, 1972, revision) used by log scaling and grading bureaus: Columbia River--Eugene, Oregon; Puget Sound--Tacoma, Washington; Gray's Harbor--Hoquiam, Washington; Southern Oregon--Roseburg, Oregon; and Northern California--Arcata, California. Copies may be obtained from any of these Bureaus.

<sup>10/</sup> Log grade descriptions for hemlock, silver, and white fir. Form R-6-2440-19D (March 1963). Unpublished material on file at U.S. Forest Service, Region 6, Portland, Ore.

*Table 5.--Log input and number of logs by diameter class as a percent  
of net Scribner and gross cubic volumes*

| Scaling<br>diameter<br>(inches) | Bandmill            |          |        | Chip-N-Saw          |          |        |
|---------------------------------|---------------------|----------|--------|---------------------|----------|--------|
|                                 | Number<br>of logs   | Scribner | Cubic  | Number<br>of logs   | Scribner | Cubic  |
|                                 | - - - Percent - - - |          |        | - - - Percent - - - |          |        |
| 4                               | 38                  | 2.82     | 3.34   | 5                   | 0.49     | 0.68   |
| 5                               | 157                 | 18.52    | 18.49  | 171                 | 24.82    | 23.90  |
| 6                               | 57                  | 10.12    | 9.89   | 92                  | 21.88    | 18.66  |
| 7                               | 64                  | 13.87    | 13.12  | 56                  | 14.29    | 18.22  |
| 8                               | 61                  | 15.71    | 17.07  | 48                  | 15.32    | 16.08  |
| 9                               | 41                  | 15.01    | 15.62  | 20                  | 8.13     | 8.26   |
| 10                              | 24                  | 11.55    | 10.49  | 18                  | 10.91    | 10.12  |
| 11                              | 7                   | 4.20     | 4.20   | 4                   | 1.91     | 1.80   |
| 12                              | 8                   | 4.81     | 4.71   | 3                   | 2.25     | 2.28   |
| 13                              | 4                   | 2.61     | 2.30   | 0                   | --       | --     |
| 14                              | 1                   | .78      | .77    | 0                   | --       | --     |
| Total                           | 462                 | 100.00   | 100.00 | 417                 | 100.00   | 100.00 |

Cubic lumber volumes in table 2 are based on sample measurements of actual rough green lumber width and thickness and nominal lumber lengths. Cubic volume of wood converted to sawdust is based on a calculation using board surface area and an average kerf for the mill. The actual kerf on the Chip-N-Saw was adjusted to compensate for the amount of board surface which was "profile" chipped and for which no kerf developed. Chippable volumes are computed by subtracting lumber and sawdust cubic volume from log cubic volume.

## PROCESSING AND INDIVIDUAL MILL SETUP

In the woods, each log was given a number identifying the tree and the log position in the tree. At the mill, lumber was identified with the mill and scaling length log and tree.

The bandmill equipment included a debarker, band headrig for primary breakdown, reciprocating gangsaw, two edgers, a vertical band resaw, and a gang trimsaw. Rough green grading and tally were done on the green chain.



The Chip-N-Saw was part of a mill complex which included a bandmill. It had a separate barker; however, the trimsaw and edger were inside the main mill. Green grading and tallying were done on the chain from the Chip-N-Saw to the main mill. Pencil trim or rip<sup>11/</sup> was also marked at this time.

## LUMBER GRADING

All lumber was given a rough green grade<sup>12/</sup> by an inspector from the West Coast Lumber Inspection Bureau or Pacific Lumber Inspection Bureau. At the Chip-N-Saw, pencil trim or rip was also designated by the grade inspector. Pencil trim or rip was used only when required to tally a board as a recognized lumber grade, not to upgrade boards.

## LUMBER TALLY

Lumber was tallied in the rough green condition by Forest Service crews working immediately after the grader. Each board was tallied by width, thickness, length, grade, and the identification number of the log. Pencil trim and rip were deducted from the actual length and width as the boards were tallied.

Because most grand fir lumber is sold surfaced dry, it was necessary to convert the lumber recovery, by log, to a dry grade and volume. This was done by developing and applying conversion factors.

Development of these conversion factors required sorting the rough dry lumber by planing item within each rough green grade. After sorting, the lumber was planed. An Association inspector then regraded the surfaced dry stock. Actual trimming for upgrading occurred at this point. Forest Service crews made separate dry tallies for each green grade sort. These tallies showed the proportion of surfaced dry grades resulting from each green grade, including cull and trim loss. Applying these factors to the grade and volume of rough green lumber in each log placed the study on a surfaced dry basis.

---

<sup>11/</sup> Reduction in board length or width, marked by the grader, when edging or trimming was necessary.

<sup>12/</sup> West Coast Lumber Inspection Bureau. Standard grading and dressing rules for Douglas-fir, West Coast hemlock, Sitka spruce, western redcedar lumber. No. 15, revised. Portland, Oreg., 1968.

## CHIP RECOVERY

At the beginning of the study an empty chip bin was provided. All study chips were put in one shipment. The oven-dry weight of the chips was determined by the chip purchaser. The total of oven-dry tons for the study was determined from the purchaser's invoice. At the Chip-N-Saw all the pencil trim or rip was excluded from the green lumber tally. Since trimming and edging were done inside the main mill, all chippable material from log end trim as well as pencil trim and rip were lost from chip totals. This volume could not have exceeded 1 oven-dry ton of chips.

## DATA COMPILATION AND ANALYSIS

The data was edited and compiled using a computer program<sup>13/</sup> developed for compiling lumber recovery data.

Statistical analyses were run to test the relationship between cubic recovery ratios and factors by log diameters at both mills. Multiple linear regressions were run, and the curve form which best fit the data was selected on the basis of the lowest mean squared error term. The mathematical model which best fit the recovery data was as follows (D = log scaling diameter):

$$\text{Bandmill:} \quad \text{Ratio} = a + \frac{b}{D} + \frac{c}{D^2}$$

$$\text{Chip-N-Saw:} \quad \text{Ratio} = a + bD + cD^2 + dD^3$$

The Chip-N-Saw curves level or drop at the end because some of the larger logs were slightly larger than the machine had been designed to handle.

Because of different curve forms, the two mills cannot be compared directly. Both sets of data were compared by analysis of covariance on each of the curve forms. The conclusion from analysis of both forms was the same. The difference in slope of the lines was not significant, but the difference in the adjusted means was significant at the 1-percent probability level for either curve. By inference, there was a significant difference in the efficiency of the processes, which varied little by log scaling diameter.

Statistical inferences about the differences in recovery ratio ([lumber tally/net log scale] x 100) are based on the curve form

$$Y = a + \frac{b}{D} + \frac{c}{D^2}$$

because this was the best fit for both mills.

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<sup>13/</sup> John W. Henley and Jill M. Hoopes. An electronic computer program for calculating saw log lumber recovery and value. USDA Forest Service, 47 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1967.



Fahey, Thomas D., and Douglas L. Hunt

1975. Lumber recovery from grand fir thinnings at a bandmill and chipping canter. USDA For. Serv. Res. Pap. PNW-186, 15 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Trees cut in thinning of a grand fir stand were processed in a bandmill and a Chip-N-Saw facility. Lumber grades produced were similar at each mill. The Chip-N-Saw as operated here produced considerably less lumber and sawdust and substantially more chips per unit of log measure.

Keywords: Lumber recovery studies, grand fir, thinnings.

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Seasonal Trends in the  
Nutritive Content of  
Important Range Forage Species  
Near Silver Lake, Oregon



O. Eugene Hickman

## ABSTRACT

Moisture, crude protein, ash, calcium, phosphorus, calcium:phosphorus ratios, crude fiber, crude fat, and apparent digestibility were determined for 15 species in three vegetal classes on seven vegetation types. These measurements were contrasted by classes, species, and type, and ungulate management inferences were drawn.

KEYWORDS: Nutrient regime (animal), range production, forage plants.

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## ACKNOWLEDGMENT

This study was conducted while the author was a graduate student at Oregon State University. Financial assistance was provided by the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The author is indebted to his former major professor, Dr. D. W. Hedrick, for much needed advice and guidance in planning and implementing this project. Sincere thanks are extended to J. Edward Dealy of the Experiment Station, Dr. J. E. Oldfield of the Oregon State University Animal Science Department, and Allen Bond, Oregon State University graduate student, for their part in assisting and guiding the author in field and laboratory work.

## INTRODUCTION

Livestock and game managers are increasingly aware of the nutritional aspects of range management. An adequate diet for range animals is essential for the efficient production of animal products.

Deficiencies in protein, phosphorus, and carotene (vitamin A) are common on western ranges (Cook and Harris 1968) and have led to studies on nutritional values of forage plants (Cook and Harris 1950a, Dietz et al. 1962, Beath and Hamilton 1952, Skovlin 1967, Vallentine and Young 1959). Such information can be used to estimate the seasonal adequacy of animal diets and is needed in order to adopt sound management practices.

A limited number of such studies have been undertaken in central Oregon by scientists of the Pacific Northwest Forest and Range Experiment Station (Dealy 1966), at the Squaw Butte Experiment Station near Burns, Oregon (Raleigh and Wallace 1965, Wallace et al. 1961), and at Oregon State University (Smith 1963, Urness 1966).

The Silver Lake mule deer winter range, 80 miles south of Bend, is important from the standpoint of big game use and livestock production. Extensive research in livestock and big game management has been conducted there but included little nutritional evaluation of native forage. Studies have included effects of big sagebrush (*Artemisia tridentata*) in deer diets (Smith 1963) and determination of crude protein levels in native grass and shrub species during winter and early spring (Urness 1966). This study was developed to:

1. Define seasonal trends for the crude protein, fiber, and fat (ether extract), moisture, ash (total mineral matter), calcium, phosphorus, and apparent digestibility in selected forage species; and

2. Determine if these trends vary between ecologically different vegetation types.

## THE STUDY AREA

The study area is 6 miles southwest of the town of Silver Lake, Oregon, in Lake County, elevation approximately 4,700 feet. It is in the forest fringe adjacent to the High Desert and typical of the Silver Lake deer winter range. Here, the Pacific Northwest Forest and Range Experiment Station and the Oregon Wildlife Commission established three 170-acre enclosures that were sampled in this study.

### Climate

The High Desert is dry, with hot summers and cold winters. Most precipitation occurs as snow, although significant rain may occur in May and June (Urness 1966). The growing season is about 79 days, with frost a possibility during any month.<sup>1/</sup>

Climatological data were obtained from the weather station at Silver Lake and are compared to 26 years of climatic records (fig. 1).

The average annual precipitation at Silver Lake is 9.9 inches (Johnsgard 1963, p. 80), which is probably lower than that at the study plots. During December 1964, midway in the study, precipitation totaled 7.68 inches, far above the average.

### Soils

Soils developed from volcanic material, including tuff and tuff breccia, hard basalt, and pumice, have been mapped and described by Herman (see footnote 1).

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<sup>1/</sup> L. D. Herman. Soil survey report for Silver Lake Experimental Range study area, Lake County, Oregon. Unpublished manuscript on file at Pacific Northwest Forest and Range Experiment Station, La Grande, Oreg., 18 p., 1965.



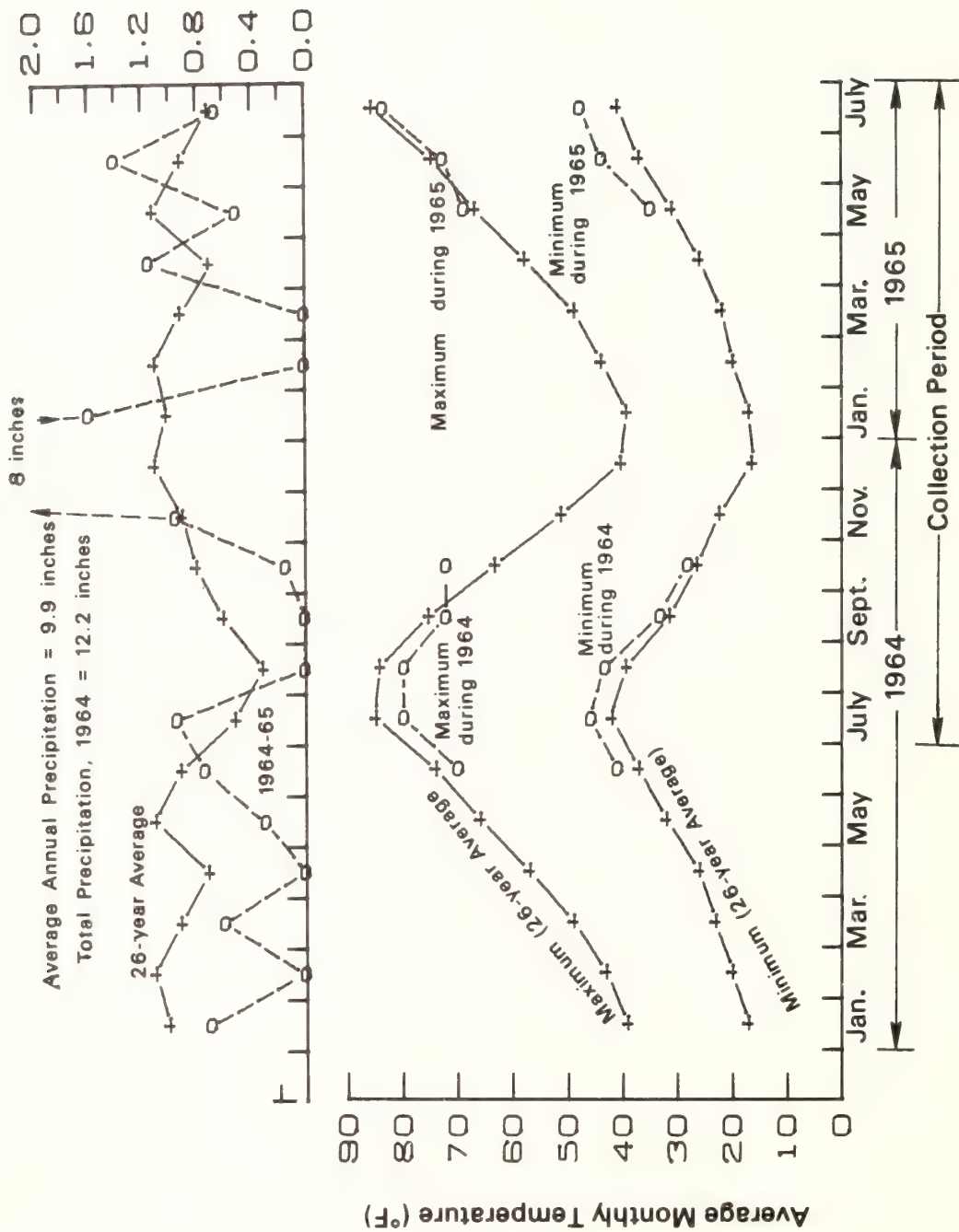


Figure 1.--Temperature and precipitation data for Silver Lake weather station.

## Vegetation Types

Vegetation types within the enclosures were delineated and described by Driscoll and Dealy<sup>2/</sup> and may be descriptively titled as:

1. *Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis*
2. *Pinus ponderosa*/*Cercocarpus ledifolius*/*Festuca idahoensis*
3. *Purshia tridentata*-*Artemisia arbuscula*/*Poa secunda*
4. *Purshia tridentata*/*Festuca idahoensis*
5. *Artemisia arbuscula*/*Agropyron spicatum*
6. *Artemisia arbuscula*/*Poa secunda*.

An area studied just outside the enclosures was dominated by western juniper (*Juniperus occidentalis*), with an understory primarily of Idaho fescue (*Festuca idahoensis*), and was named:

7. *Juniperus occidentalis*/*Festuca idahoensis*.

## Livestock and Game Use

The mule deer herd moves to this winter range in mid-December and leaves in mid-April. A small herd is resident year-round.

Livestock are regulated by cow-calf permits issued by the U.S. Forest Service. The grazing season was from late May until the beginning of July.

---

<sup>2/</sup> R. S. Driscoll and J. E. Dealy. A study to investigate the foraging habits of mule deer and cattle and factors affecting them on the Silver Lake herd range. Unpublished manuscript on file at Pacific Northwest Forest and Range Experiment Station, La Grande, Oreg., 27 p., 1964.

## METHODS AND PROCEDURES

### Species Selection

The species studied are shown in table 1. Grasses and browse species were selected based on their abundance and importance as forage for deer and/or livestock.

Forbs were less plentiful, so emphasis was on abundance. Mountain lily (*Leucocrinum montanum*) had considerable use, probably by deer. The importance of the other forbs as forage is uncertain. They are representative of forbs available to deer and/or cattle during the spring and summer.

### Sampling Dates and Techniques

The study period, July 1964 through July 1965, included 15 sampling dates and was planned to include one complete annual cycle for the species selected. Consequently, sampling was scheduled by growth stages of important species.

All species were collected by vegetation types (table 1). Several species were important in more than one type: bitter brush (*Purshia tridentata*), squirreltail (*Sitanion hystrix*), and Idaho fescue. Ecotones were avoided in the collections.

Only one species, Idaho fescue, was collected from the *Juniperus occidentalis*/*Festuca idahoensis* type. Idaho fescue grows vigorously around the base of juniper trees. Although accessible to livestock, it is sometimes lightly used or untouched. Idaho fescue was collected from these microsites and compared with collections of the same species from other types.

Clipping was done to approximate grazing and included only current annual growth except for mountain mahogany (*Cercocarpus ledifolius*), which included previous years' leaves.

Table 1.---Species selected for sampling (\*) and other plants referred to in this report (scientific nomenclature follows Hitchcock (1950) for grasses and Peck (1961) for other species)

| Scientific name                                                          | Common name           | Vegetation type where sampled                                                      |
|--------------------------------------------------------------------------|-----------------------|------------------------------------------------------------------------------------|
| <b>Grasses and Grasslike</b>                                             |                       |                                                                                    |
| <i>Agropyron spicatum</i> (Pursh)<br>Scribn. and Smith                   | Bluebunch wheatgrass* | <i>Artemisia arbuscula</i> / <i>Agropyron spicatum</i>                             |
| <i>Purshia hessii</i> Boott                                              | Ross' sedge*          | <i>Pinus ponderosa</i> / <i>Purshia tridentata</i> / <i>Festuca idahoensis</i>     |
| <i>Festuca idahoensis</i> Elm.                                           | Idaho fescue*         | <i>Pinus ponderosa</i> / <i>Purshia tridentata</i> / <i>Festuca idahoensis</i>     |
| <i>Koeleria cristata</i> (L.) Pers.                                      | Junegrass*            | <i>Artemisia arbuscula</i> / <i>Agropyron spicatum</i>                             |
| <i>Poa secunda</i> Presl.                                                | Sandberg bluegrass*   | <i>Artemisia arbuscula</i> / <i>Agropyron spicatum</i>                             |
| <i>Sitanion hystrix</i> J. G. Smith                                      | Squirreltail*         | <i>Purshia tridentata</i> - <i>Artemisia arbuscula</i> / <i>Poa secunda</i>        |
| <i>Stipa thurberiana</i> Piper                                           | Thurber needlegrass*  | <i>Purshia tridentata</i> - <i>Artemisia arbuscula</i> / <i>Poa secunda</i>        |
| <b>Forbs</b>                                                             |                       |                                                                                    |
| <i>Delphinium Nuttallianum</i> Pritz.                                    | Upland larkspur*      | <i>Purshia tridentata</i> / <i>Festuca idahoensis</i>                              |
| <i>Lilium montanum</i> Nutt.                                             | Mountain lily*        | <i>Artemisia arbuscula</i> / <i>Poa secunda</i>                                    |
| <i>Senecio integerrimus</i> Nutt. var.<br><i>exaltatus</i> (Nutt.) Cron. | Tall western senecio* | <i>Pinus ponderosa</i> / <i>Purshia tridentata</i> / <i>Festuca idahoensis</i>     |
| <i>Sidalcea oregana</i> (Nutt.) Gray                                     | Oregon sidalcea*      | <i>Purshia tridentata</i> / <i>Festuca idahoensis</i>                              |
| <b>Shrubs</b>                                                            |                       |                                                                                    |
| <i>Artemisia arbuscula</i> Nutt.                                         | Scabland sagebrush*   | <i>Artemisia arbuscula</i> / <i>Poa secunda</i>                                    |
| <i>Artemisia tridentata</i> Nutt.                                        | Big sagebrush*        | <i>Purshia tridentata</i> / <i>Festuca idahoensis</i>                              |
| <i>Cercocarpus ledifolius</i> Hook.                                      | Mountain mahogany*    | <i>Pinus ponderosa</i> / <i>Cercocarpus ledifolius</i> / <i>Festuca idahoensis</i> |
| <i>Juniperus occidentalis</i> Hook.                                      | Western juniper       | --                                                                                 |
| <i>Pinus ponderosa</i> Dougl.                                            | Ponderosa pine        | --                                                                                 |
| <i>Purshia tridentata</i> (Pursh) DC.                                    | Bitter brush*         | <i>Pinus ponderosa</i> / <i>Purshia tridentata</i> / <i>Festuca idahoensis</i>     |

Composite samples (per observation) were made by collecting small amounts of material from plants (20-40) that were well distributed through each vegetation type. Subsequent samples taken at later sampling dates were from the same general area in each type but not necessarily from the same individual plants. Average growth stage was estimated for each composite sample.

All material was placed in airtight plastic bags after collection and taken to the laboratory (1-2 days later) for weighing and subsequent chemical analyses.

## Methods of Analysis

Samples were analyzed for crude protein, fiber, and fat (ether extract) and for ash (total mineral matter) by methods approved by the Association of

Official Agricultural Chemists (1965).

Samples analyzed for calcium and phosphorus were dry ashed.<sup>3/</sup> Calcium was determined by atomic absorption spectroscopy (Willis 1960) and phosphorus by the Vanadomolybdophosphoric yellow color method in a sulfuric acid system (Jackson 1958).

Apparent digestibility (dry matter disappearance) was determined by the artificial rumen technique of Smith (1963) and Bedell (1966). Rumen juice was collected at midday from a fistulated steer having free access to grass hay and water and then used in a 24-hour digestion period. One 48-hour period was utilized for a comparison of these two treatments.

<sup>3/</sup> Personal communication with Dr. O. C. Compton, Oregon State University, Corvallis.

## RESULTS AND DISCUSSION

The data have been summarized graphically for several species to give a picture of seasonal trends and relationships among constituents.

Nutrient content is only one of several criteria that should be used to judge the value of a forage plant. Data presented here will be most useful when related to other important factors such as species abundance, season of use, and palatability.

### Nutrient Relationships by Vegetal Classes

#### GRASSES AND SEDGES

Calcium, phosphorus, crude protein, apparent digestibility, and moisture are associated in the grass and sedge species. Trends were similar throughout the season (figs. 2 and 3). An early spring increase in moisture was accompanied by similar increases in other constituents. Maximum moisture content occurred before the boot stage. This was followed by a downward trend with nutrients leveling off later in the season. Results are similar to those of Skovlin (1967) and Whitman et al. (1951).

Gordon and Sampson (1939) found a continuous and orderly decline in crude protein, calcium, and phosphorus from the earliest appearance of leaf blades to maturity in grasses. Wallace and Raleigh (1962) found that both apparent digestibility and crude protein of crested wheatgrass (*Agropyron cristatum*) decreased significantly as the forage matured. The trend in apparent digestibility reported here for Idaho fescue is similar to that of Pearson (1964) for Arizona fescue (*Festuca arizonica*), although absolute values are greater.

Moisture content remained high from early leaf stage until anthesis (flowering) in the grasses and from early leaf stage until seed formation

in the sedge. After these stages were reached, moisture decreased rapidly. The rate of loss of other constituents were inverse to this. In general, calcium, phosphorus, crude protein, and apparent digestibility decreased at a rapid rate when moisture loss was minimal. Gordon and Sampson (1939) reported that the most rapid change in nutrient content took place between the periods of leaf development and full bloom. When moisture began to decrease at a faster rate, the other constituents tended to level off or slow their rate of decrease, Sandberg bluegrass (*Poa secunda*) excepted. For this species, apparent digestibility decreased as rapidly as moisture.

Although calcium and phosphorus decreased with plant maturity, the ratio of calcium to phosphorus widened as calcium decreased at a slower rate than phosphorus. Compared with moisture content, the calcium:phosphorus ratio was narrow when the moisture content was high and widest when moisture content was low.

Seasonal trends of crude fiber and ash were opposite to those for calcium, phosphorus, crude protein, apparent digestibility, and moisture. Crude fiber and ash increased during the season at roughly parallel rates (except for ash content decline in some species during early summer). Gordon and Sampson (1939) found that crude fiber was lowest in grasses during early plant growth and highest at maturity. Vallentine and Young (1959) showed crude fiber negatively related to crude protein content in grasses.

Crude fat content of grasses showed no relationship with other nutrients except for a slight but temporary drop in both crude fat and ash in some species at anthesis. This is consistent with studies of Kentucky bluegrass (*Poa pratensis*) where plant development showed no effect on crude fat content (McEwen and Dietz 1965).



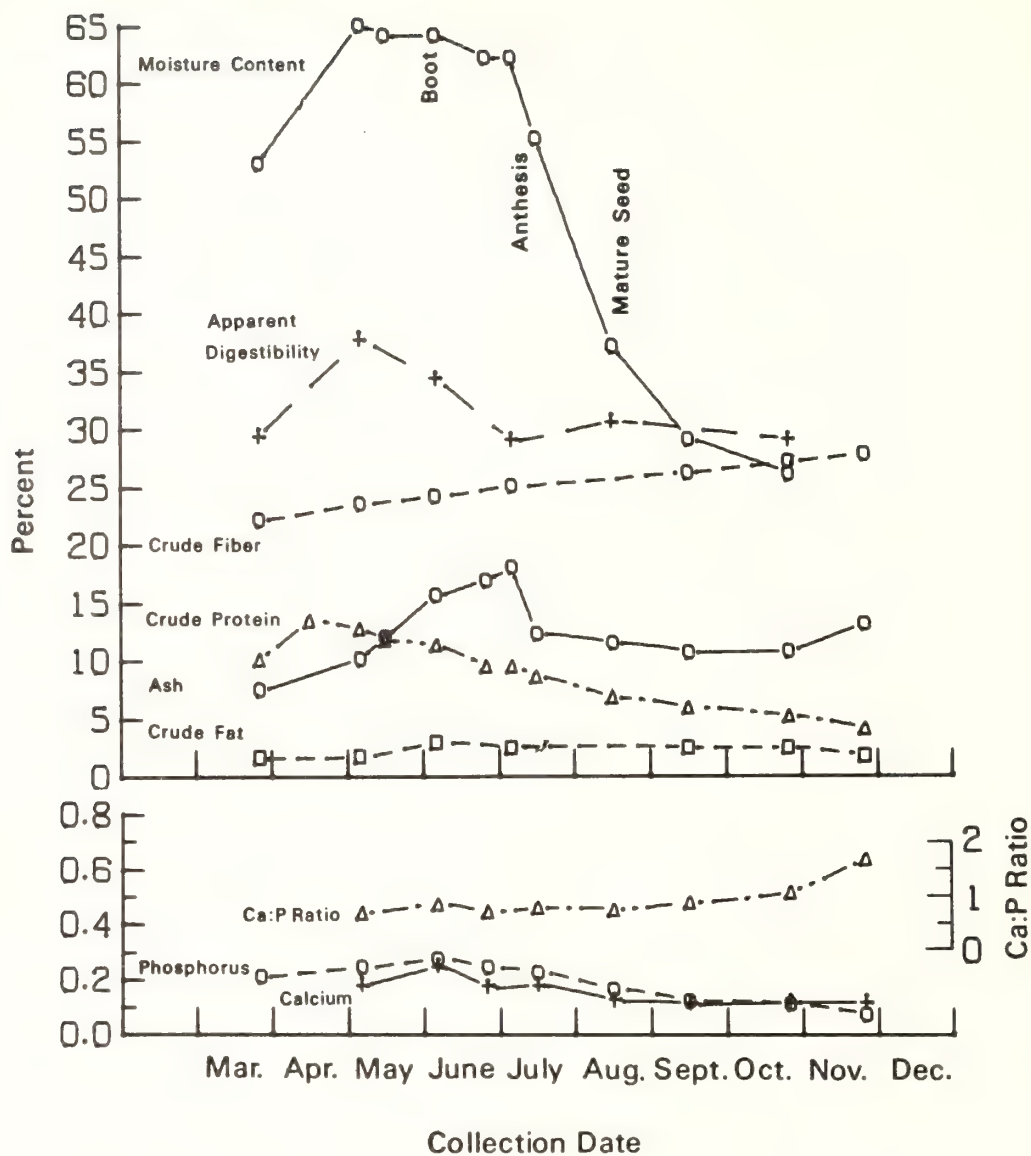


Figure 2.--Seasonal trends of constituents in Idaho fescue (*Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis*).



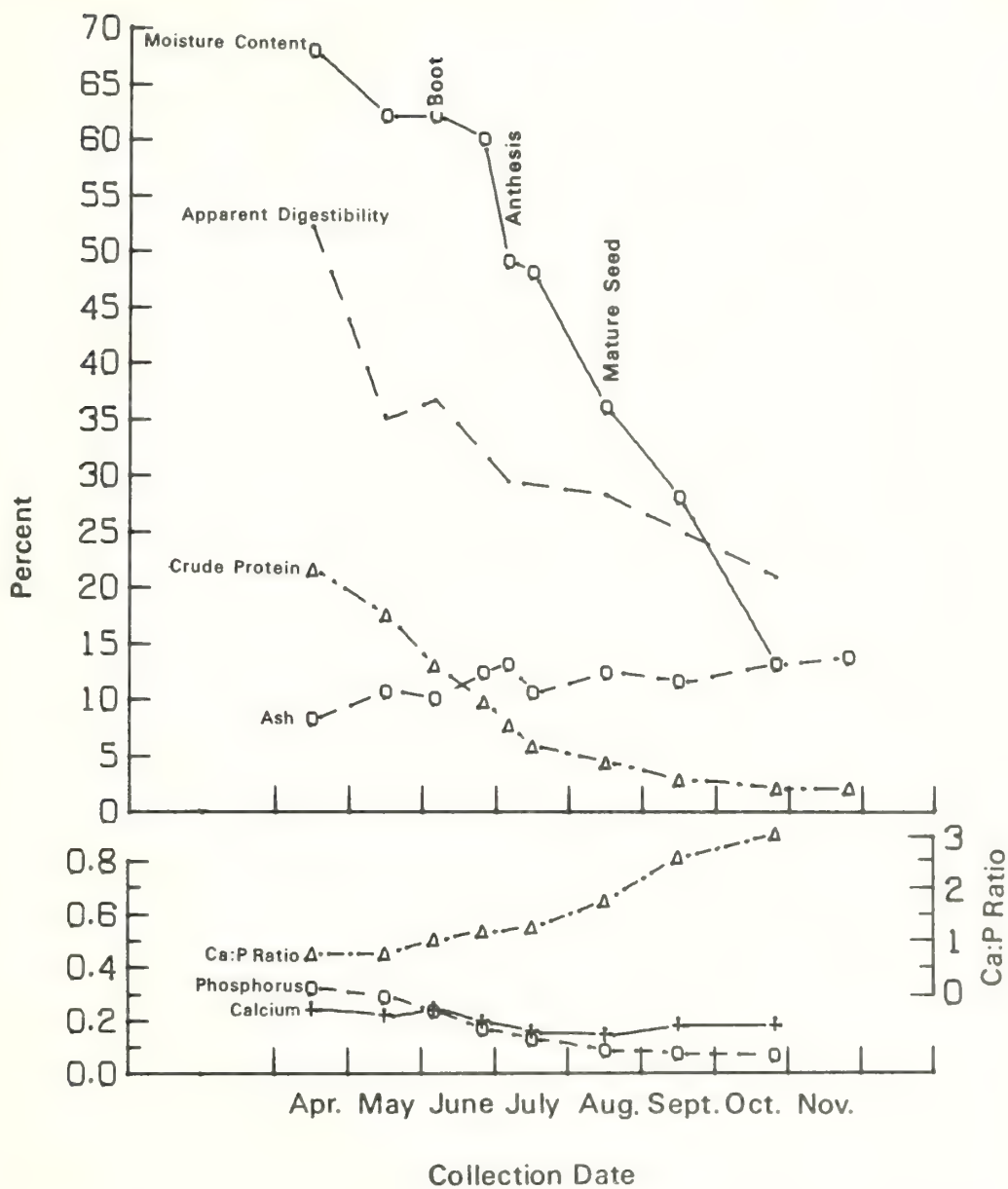


Figure 3.--Seasonal trends of constituents in bluebunch wheatgrass (*Artemisia arbuscula*/*Agropyron spicatum*).

## SHRUBS

Seasonal trends for phosphorus, ash, crude protein, and moisture showed association for shrub species reaching a peak during spring and a low point in fall or winter (figs. 4 and 5). Studies in Virginia exhibited the same pattern (Hundley 1959). Dietz et al. (1962) described similar trends for crude protein and phosphorus in shrubs in Colorado.

The calcium:phosphorus ratio for shrubs was narrow when moisture content was high and widest when moisture content was low.

There were several differences between shrubs and grasses:

1. Crude fat showed a seasonal trend the reverse of phosphorus, ash, protein, and moisture. In the grasses, crude fat had no consistent relationship to other nutrients.

2. The seasonal trend of ash was similar to phosphorus, protein, and moisture. Ash trends were the reverse of these constituents in the grasses.

3. Apparent digestibility and crude fiber trends varied widely among species. In bitter brush and mountain mahogany, crude fiber was the reverse of apparent digestibility in agreement with the results of Dietz et al. (1962). Sagebrush (*Artemisia* spp.) did not follow this pattern, and crude fiber curves were unrelated or similar to digestibility curves.

4. Calcium was variable and showed no consistent trends among all shrub species.

5. Growth stages varied in relationship to moisture and other nutrients in shrubs. For example, bitter brush and mountain mahogany flowered in spring while moisture was increasing and before maximum water content was reached, and the sagebrushes flowered in fall while moisture was lowest. In contrast, grasses flowered after the period of maximum water content while moisture was decreasing.

## FORBS

The number of samples was inadequate to show complete seasonal trends in nutrients in forbs (fig. 6) which were available for grazing for only a short period. Despite this, data show that:

1. Moisture content remained high during the sampling period (the period forbs are most likely to be grazed).

2. Apparent digestibility was high and decreased with maturity as did crude protein.

3. Calcium content and the calcium:phosphorus ratio increased with maturity.

## Species Comparisons

Individual species are compared at various seasons on the basis of their phenology (table 2) and content of specific nutrients (below).

### MOISTURE

Moisture trends for grasses and sedge are shown in figure 7. Species with the highest moisture content at the beginning of spring sampling were the lowest at maturity. Those with a low moisture content early in spring ended with a high level at maturity. After midsummer, Ross' sedge (*Carex Rossii*) remained higher in moisture than the grasses. The value of sedges as range forage is enhanced by high succulence late in the season when grasses and forbs are nearly dry (Gordon and Sampson 1939).

A generalized moisture curve is presented in figure 8. This curve summarizes the data of figure 7 for four grasses.

Note that moisture content is high but is decreasing slightly at the boot stage. During anthesis, moisture begins a rapid decline which continues through seed formation and seed maturity.

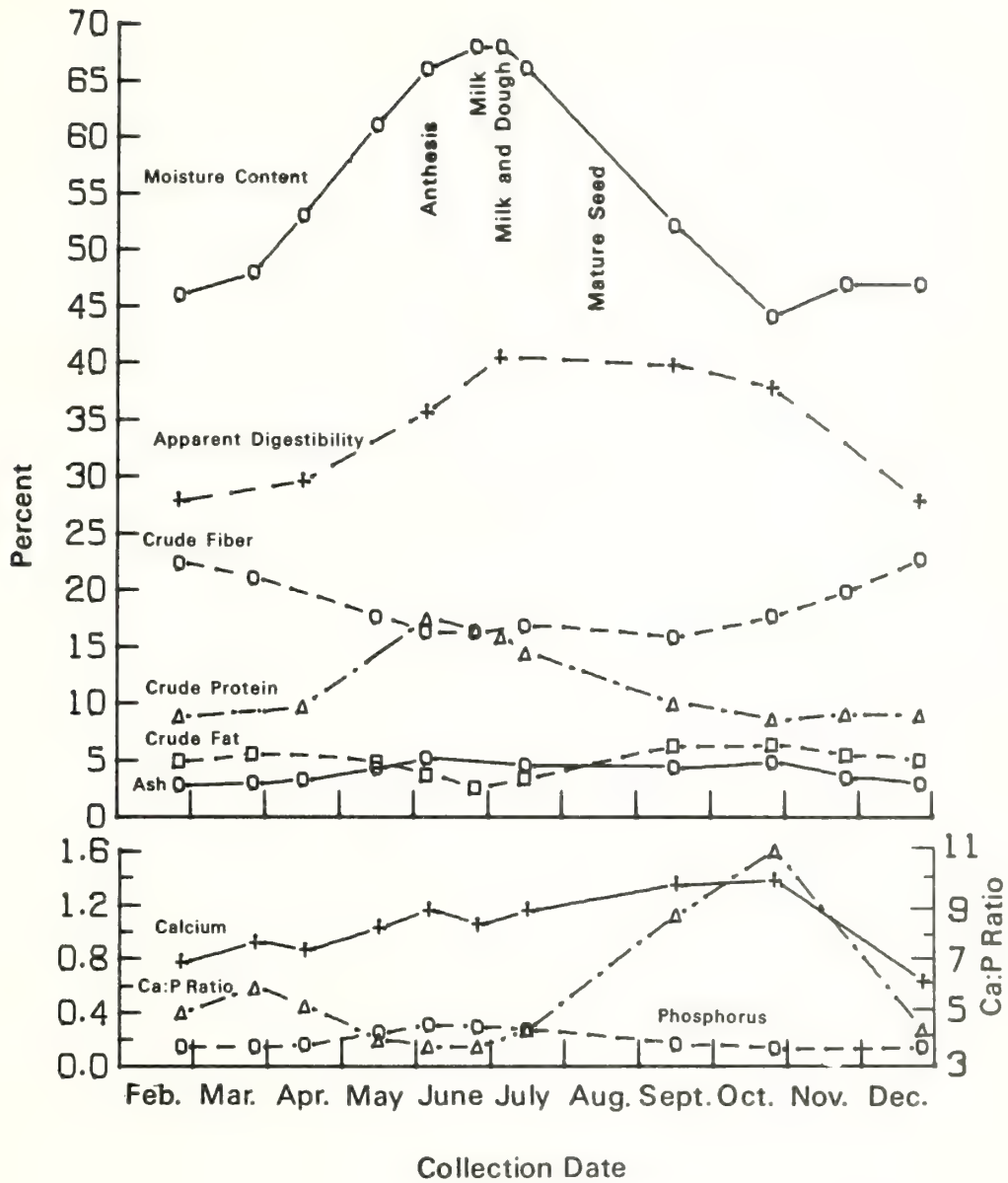


Figure 4.--Seasonal trends of constituents in bitter brush (*Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis*).

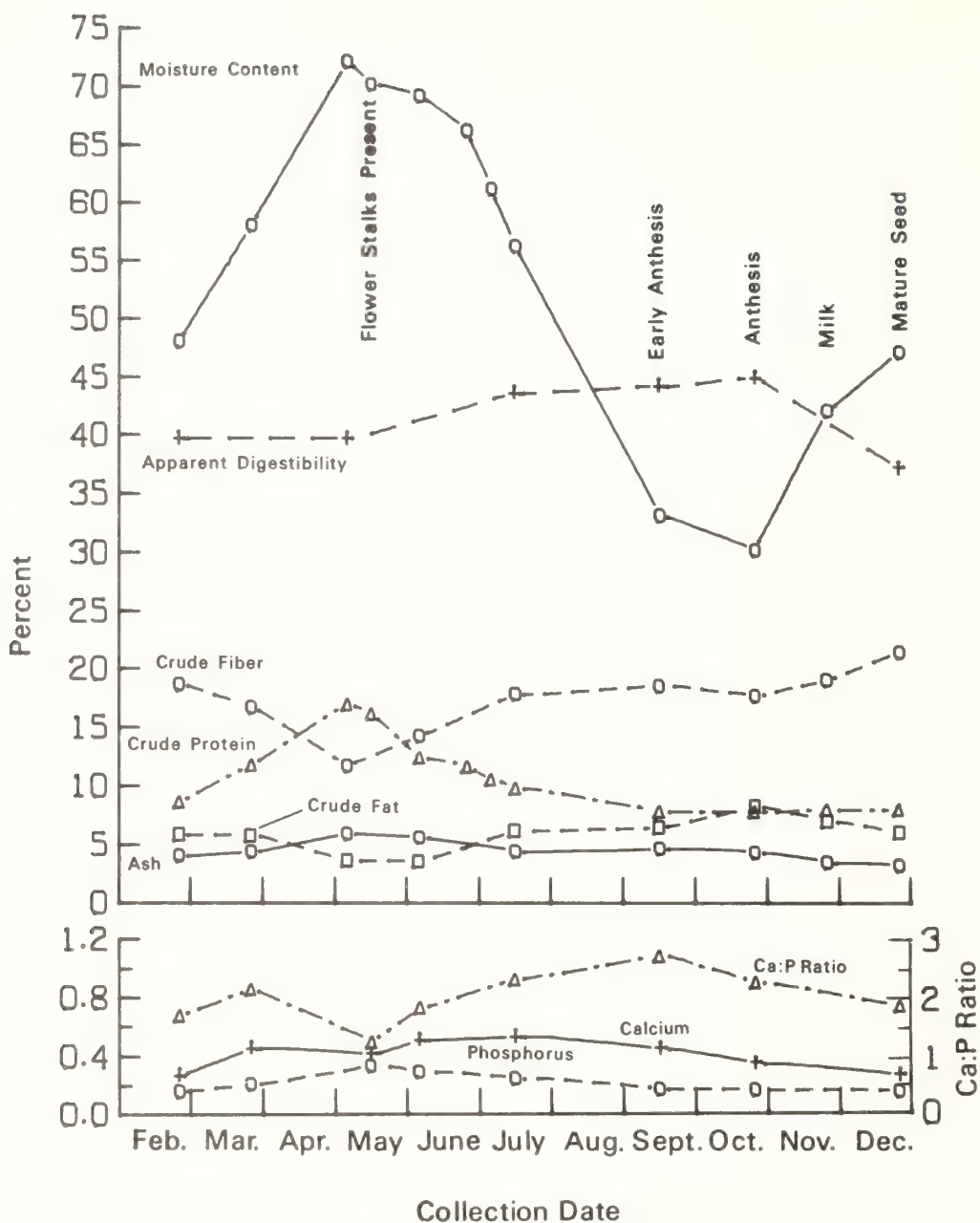


Figure 5.--Seasonal trends of constituents in scabland sagebrush (*Artemisia arbuscula*/*Poa secunda*).

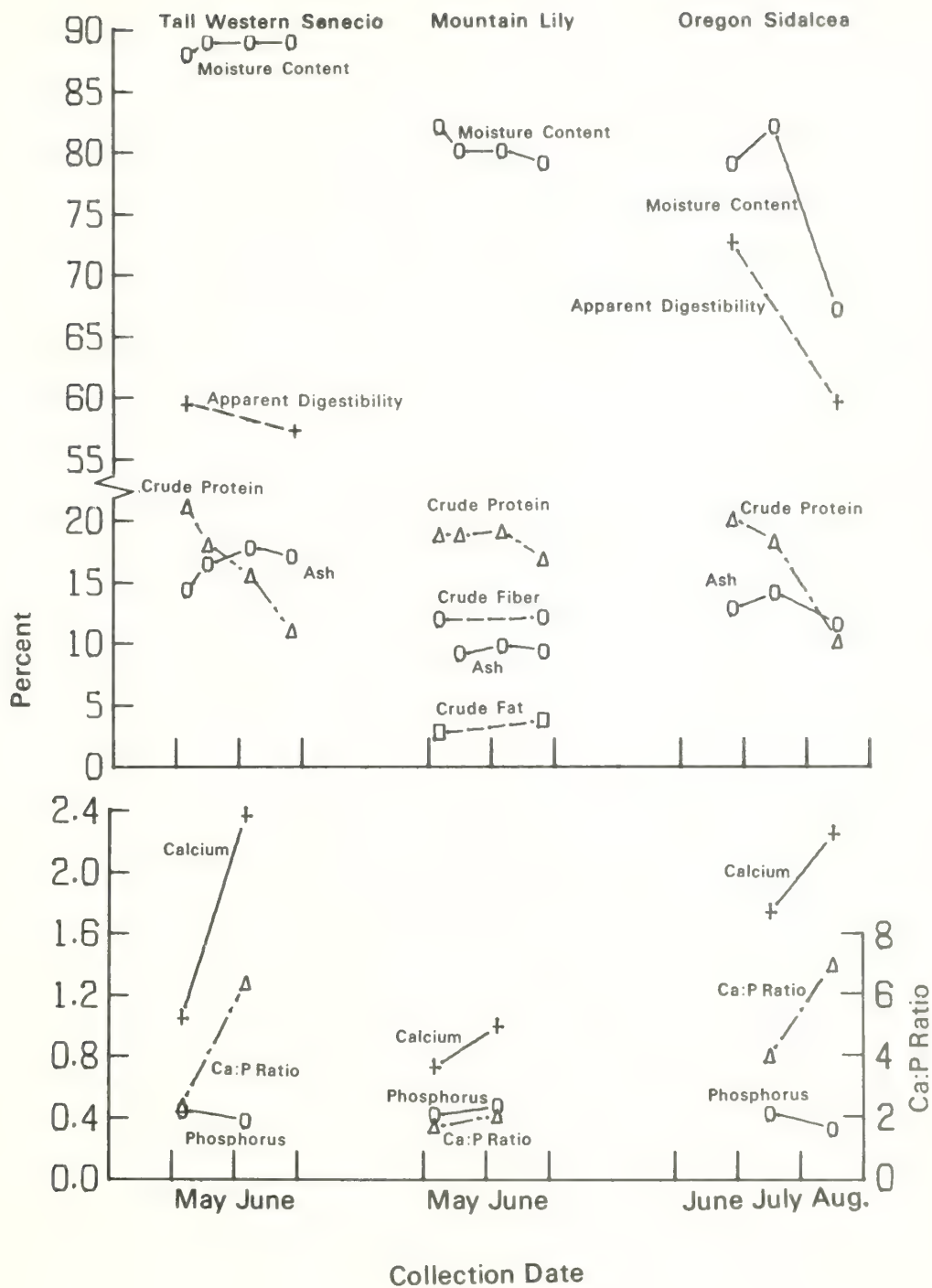


Figure 6.--Seasonal trends of constituents in tall western senecio, mountain lily, and Oregon sidalcea.



**Table 2.--Average growth stage of species at time of collection**

| Species                   | Mid-April | Early May     | Mid-May           | Late May      | Early June      | Late June     | Early July      | Mid-July                | Mid-August  | Mid-Sept.      | Late Oct.      | Late Nov.     | Late Dec.   |
|---------------------------|-----------|---------------|-------------------|---------------|-----------------|---------------|-----------------|-------------------------|-------------|----------------|----------------|---------------|-------------|
| <u>Grasses</u>            |           |               |                   |               |                 |               |                 |                         |             |                |                |               |             |
| Sandberg bluegrass        |           | boot          |                   | late anthesis |                 | mature seed   |                 | dry                     |             |                |                |               |             |
| Ross' sedge <sup>1/</sup> |           |               | anthesis          |               | dough           | late dough    | mature seed?    |                         |             |                |                |               |             |
| Thurber needlegrass       |           |               | early boot        |               | in head         | early milk    | late milk       | late dough -mature seed | mature seed |                |                |               |             |
| Squirreltail              |           |               |                   |               | boot            | anthesis      | early milk      | dough                   | mature seed |                |                |               |             |
| Junegrass                 |           |               |                   |               | boot            |               | anthesis        |                         |             |                |                |               |             |
| Bluebunch wheatgrass      |           |               |                   |               | boot            |               | anthesis        | late dough -mature seed | mature seed |                |                |               |             |
| Idaho fescue              |           |               |                   |               | boot            |               | anthesis        | dough                   | mature seed |                |                |               |             |
| <u>Forbs</u>              |           |               |                   |               |                 |               |                 |                         |             |                |                |               |             |
| Mountain lily             |           | anthesis      | late anthesis     |               | milk            | dough         |                 |                         |             |                |                |               |             |
| Upland larkspur           |           |               | anthesis          |               |                 |               |                 |                         |             |                |                |               |             |
| Tall western senecio      |           | flower stalks | buds closed       |               | anthesis        | post-anthesis |                 | mature seed             |             |                |                |               |             |
| Oregon sidalcea           |           |               |                   |               |                 | buds closed   |                 | anthesis                | mature seed |                |                |               |             |
| <u>Shrubs</u>             |           |               |                   |               |                 |               |                 |                         |             |                |                |               |             |
| Mountain mahogany         | few buds  | many buds     | anthesis          |               |                 | late milk     | dough           | dough                   | mature seed |                |                |               |             |
| Bitter brush              |           |               |                   |               | anthesis        | milk          | milk-dough      | anthesis-milk           | mature seed |                | leaves brittle |               |             |
| Scabland sagebrush        |           |               | flower stalks     |               | stalks enlarged |               |                 |                         |             | early anthesis | anthesis       | anthesis-milk | mature seed |
| Big sagebrush             |           |               | vegetative growth |               |                 | flower stalks | stalks enlarged |                         |             | early anthesis | anthesis       | anthesis-milk | mature seed |

<sup>1/</sup> Growth stage determinations were questionable because few seed heads were produced.

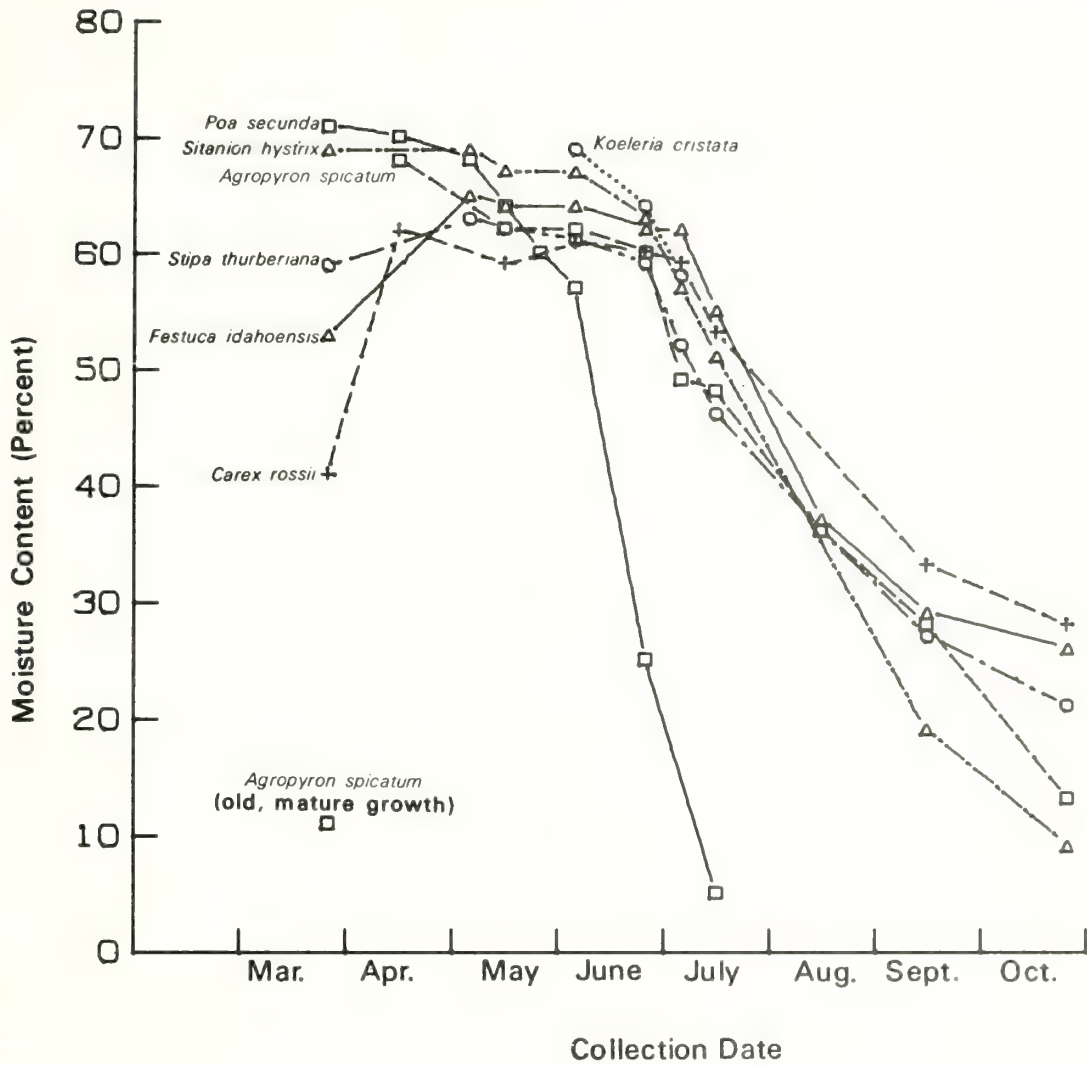


Figure 7.--Seasonal moisture trends in herbaceous species.

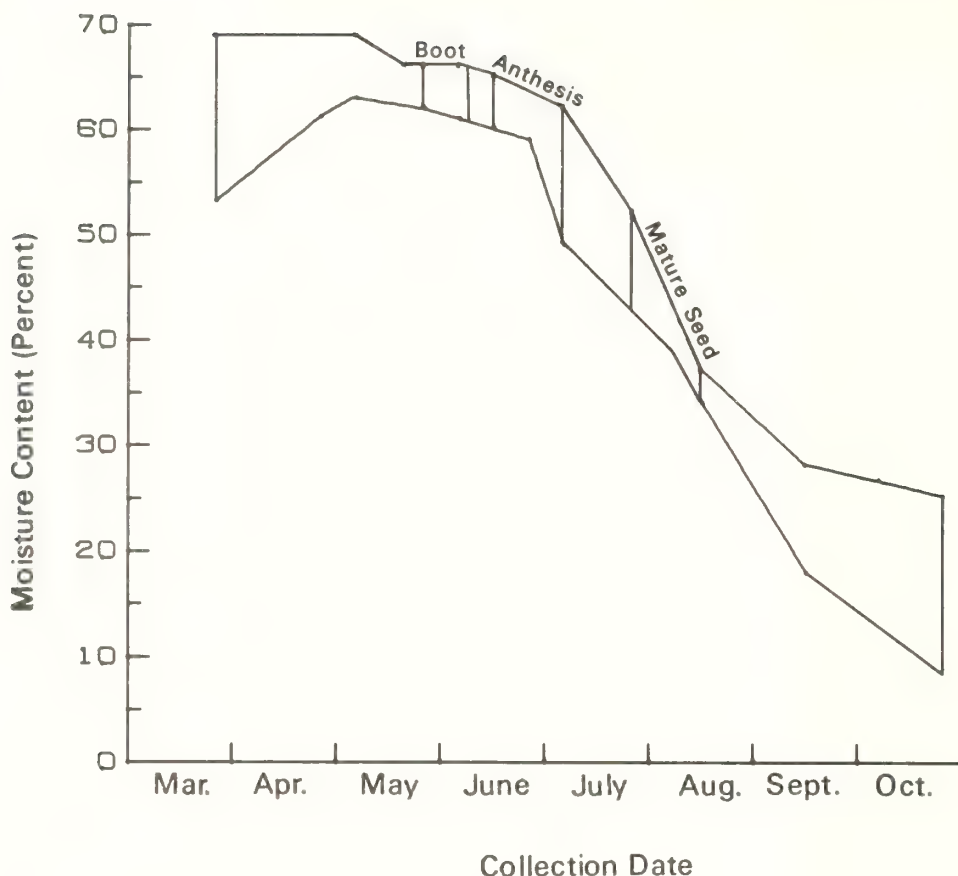


Figure 8.--Moisture curve which summarized the data presented in figure 7 for Idaho fescue, Thurber needlegrass, bluebunch wheatgrass, and squirreltail.

Each shrub had a distinct moisture curve (fig. 9).

Forbs were higher in moisture content than grasses or shrubs and showed little change during sampling, but dried rapidly after maturity.

#### CRUDE PROTEIN

All grasses were high in crude protein during the early spring (fig. 10). However, Sandberg bluegrass, squirreltail, and bluebunch wheatgrass were higher than the other species at the earliest sampling dates when deer probably make considerable use of green grass. Idaho fescue contained about half as much protein as these species during this period.

Bluebunch wheatgrass had the lowest crude protein content among the grasses from flowering (in July) through maturity. Thurber needlegrass had the highest crude protein content among the grasses during this period.

Ross' sedge contained less protein than the grasses in March and April. Afterwards, it followed a trend similar to that of Idaho fescue but ended the season higher in protein than any of the grasses.

Those grasses with lowest protein levels in early spring had the highest levels in the fall. This same relationship prevailed for moisture content.

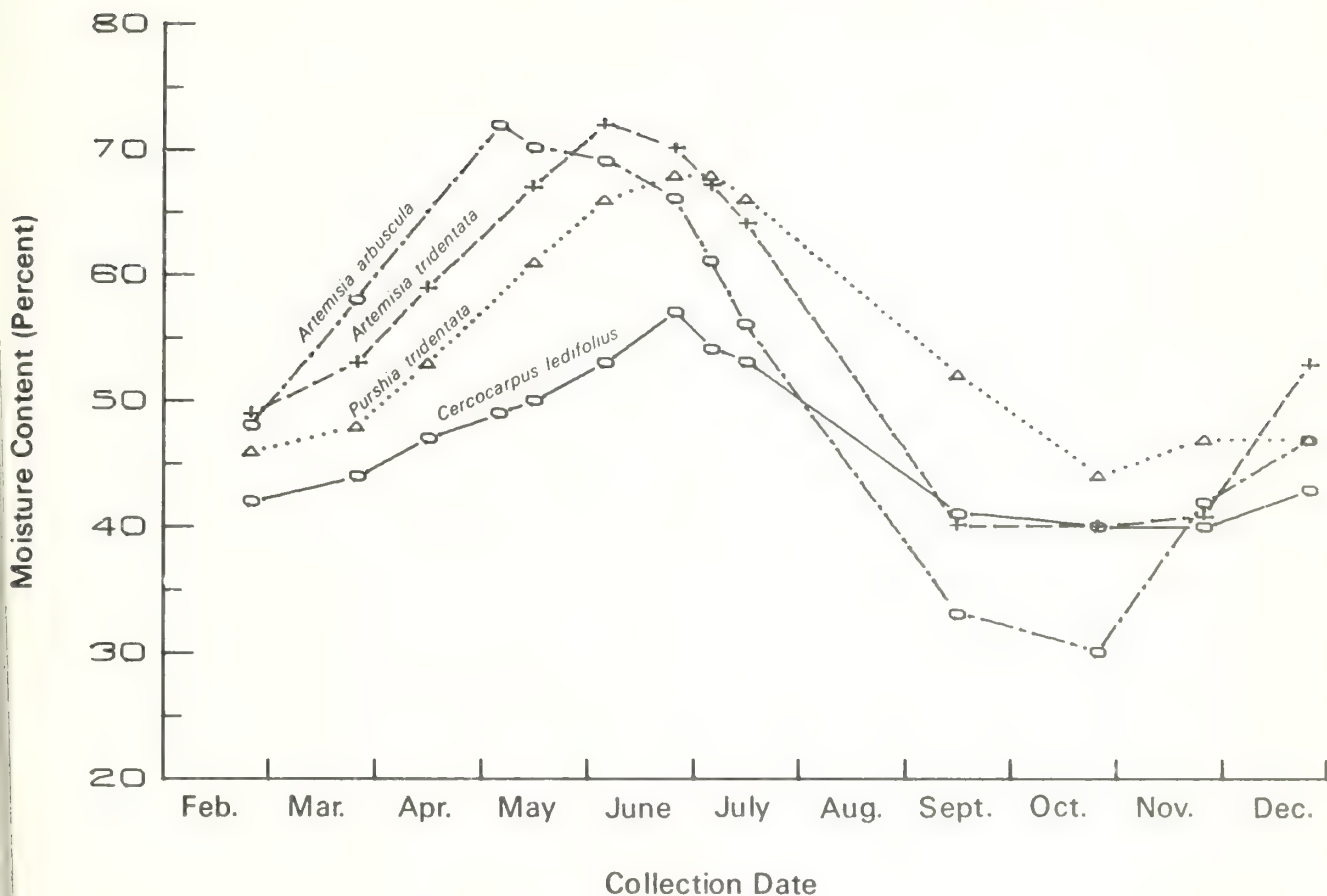


Figure 9.--Seasonal moisture trends in shrubs.

Urness (1966) determined that crude protein levels during the winter exceeded 10 percent for several range grasses growing near Silver Lake. Squirreltail, bluebunch wheatgrass, and Sandberg bluegrass were high (18-25 percent), while winter growth of Idaho fescue was lower (10-14 percent) with 8-10 percent for Ross' sedge.

Skovlin (1967) reported different results for summer collections of Idaho fescue and bluebunch wheatgrass in the Blue Mountains. Protein trends for these species were nearly parallel, and wheatgrass averaged 1 percent more than fescue. Wheatgrass contained 2 to 3 percent less protein than fescue during summer in the Silverlake study.

Similar to the results of Urness (1966), browse species ranged from 8 to 10 percent crude protein during the winter period. During the spring, protein levels were higher but varied considerably between species. By late summer, crude protein dropped to the 8- to 10-percent level, where it remained the rest of the season.

Seasonal variation in protein (difference between highest and lowest level) for grass species ranges from 9 percent in Idaho fescue to 20 percent in bluebunch wheatgrass. Variation within the shrubs was much less. Scabland sagebrush had the greatest variation (9 percent). Mountain mahogany varied least (2.6 percent).

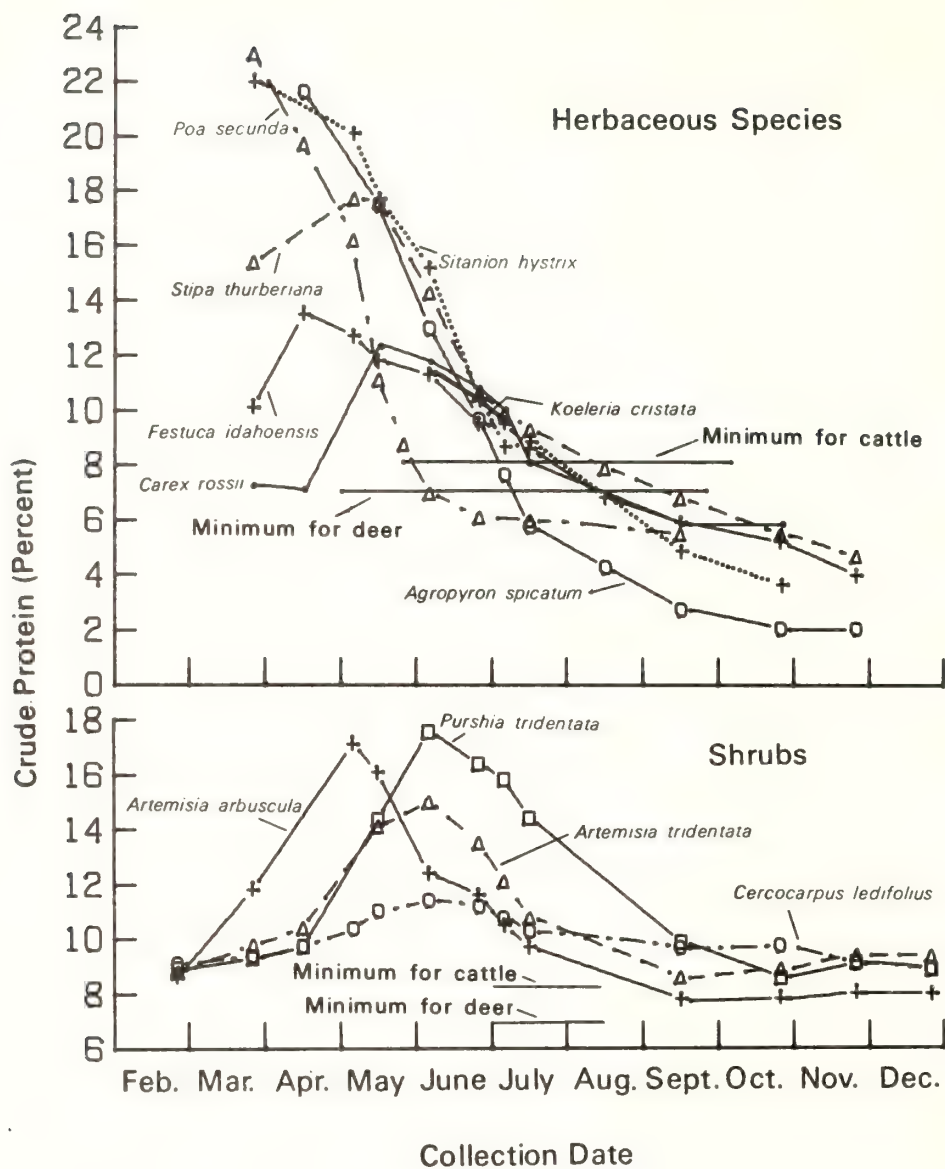


Figure 10.--Seasonal trends of crude protein.



Forbs were higher in crude protein than either grasses or browse species during the sampling. Mountain lily retained most of its protein, but others tended to drop in protein as they matured.

Whitman et al. (1951) suggested crude protein levels of 8.3 percent in range forage would meet the requirements of 900- to 1,100-pound nursing cows, indicating green grass met the protein requirement of cattle during the livestock grazing season used during the study.

Sandberg bluegrass and bluebunch wheatgrass became deficient in protein during anthesis. Idaho fescue, Thurber needlegrass, and squirreltail became deficient sometime during the early or middle stages of seed formation.

Ross' sedge exceeded the protein requirement only during May, June, and early July. Forbs were adequate during the short period available for grazing.

The shrubs (fig. 10) contained adequate protein throughout the study, except for a slight deficiency in Scabland sagebrush from September through January. Shrubs contained more protein than grasses throughout summer and fall. They would be an important protein source to cattle if grazing occurred during this period. Cook and Harris (1968) observed that browse consumption by cattle increased as the summer grazing season progressed in Utah. This late browsing tendency, along with the high protein content of shrubs at this time, suggests limiting late season grazing to browse ranges. The practicality of using protein supplements on nonbrowse ranges, as well as potential wildlife-livestock conflicts on browse ranges, may make this alternative less desirable.

The minimum level of crude protein required in the diet for deer is 6 to 7 percent (Dietz 1965). At a

minimum requirement of 7 percent, Sandberg bluegrass became deficient in early June and bluebunch wheatgrass in early July. The other grasses, including Ross' sedge, would be satisfactory until later in the summer. The shrubs met the minimum requirement for protein throughout the entire year.

#### ASH (TOTAL MINERAL MATTER)

Herbaceous species were higher in ash content than shrubs at all sampling dates (fig. 11). They ranged between 7 and 18 percent, depending on species and development stage. There was considerable variation among and within species which was difficult to interpret.

Woody species ranged from 2 to 6 percent ash throughout the season (fig. 11) which is similar to results reported by Dietz et al. (1962). All species had similar but distinct trends, and mountain mahogany exhibited the least seasonal variation.

#### CALCIUM

The grasses (and Ross' sedge) ranged between 0.1 and 0.4 percent calcium throughout the sampling period (fig. 12). Sandberg bluegrass had the highest calcium content during the early spring period, with Ross' sedge lowest. The sedge was higher than the grasses by anthesis (May) and remained high most of the summer and fall. Idaho fescue had the lowest calcium content among the grasses during the late summer and fall period.

Shrubs contained more calcium than grasses and exhibited greater variation among species (fig. 12). Scabland sagebrush had the lowest calcium content of the shrubs. It was closely paralleled by big sagebrush which remained slightly higher. Mountain mahogany was the highest of the shrubs in calcium except during the early fall when it was surpassed by bitter brush.

Three forbs were analyzed for

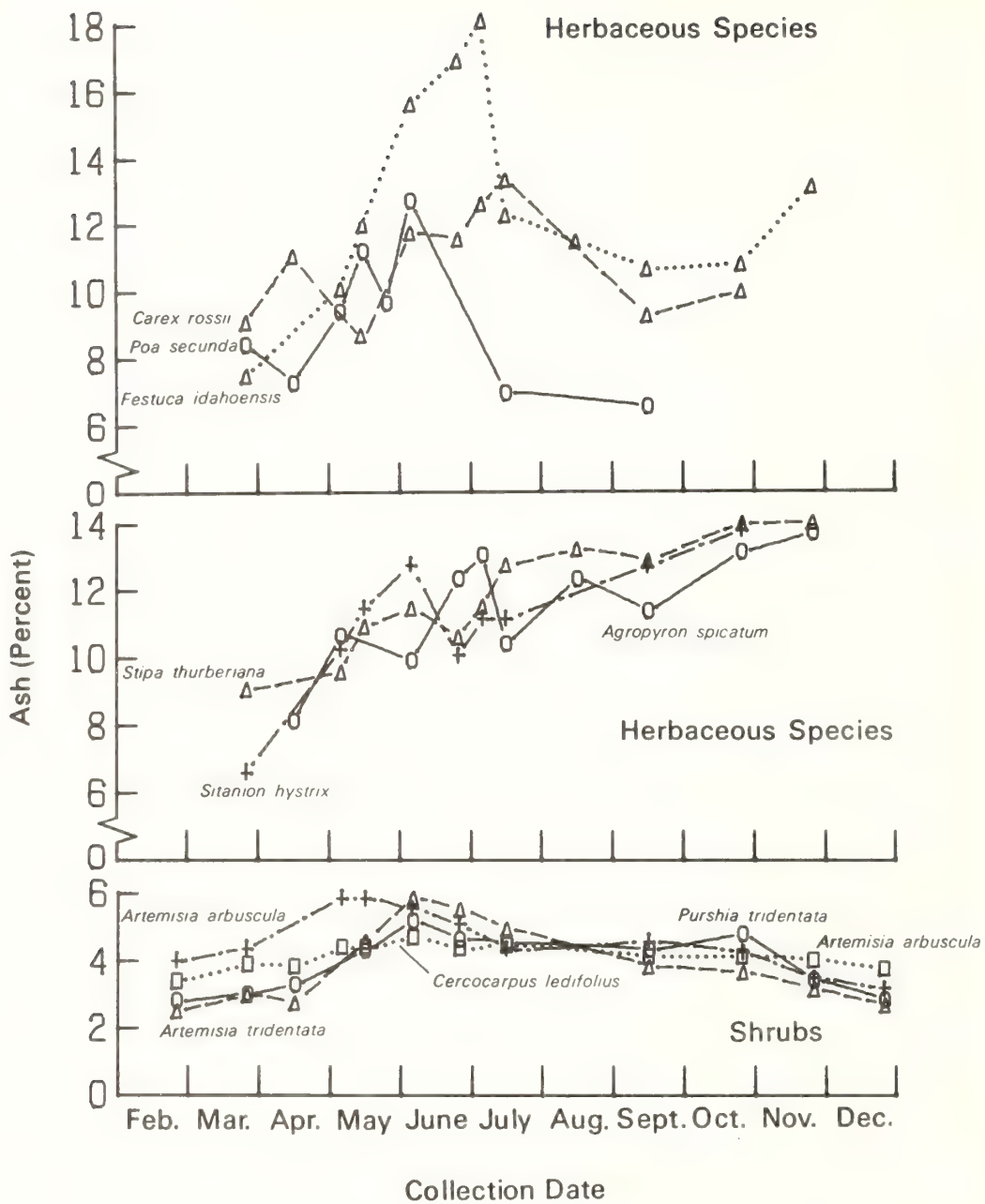


Figure 11.--Seasonal trends of ash (total mineral matter).

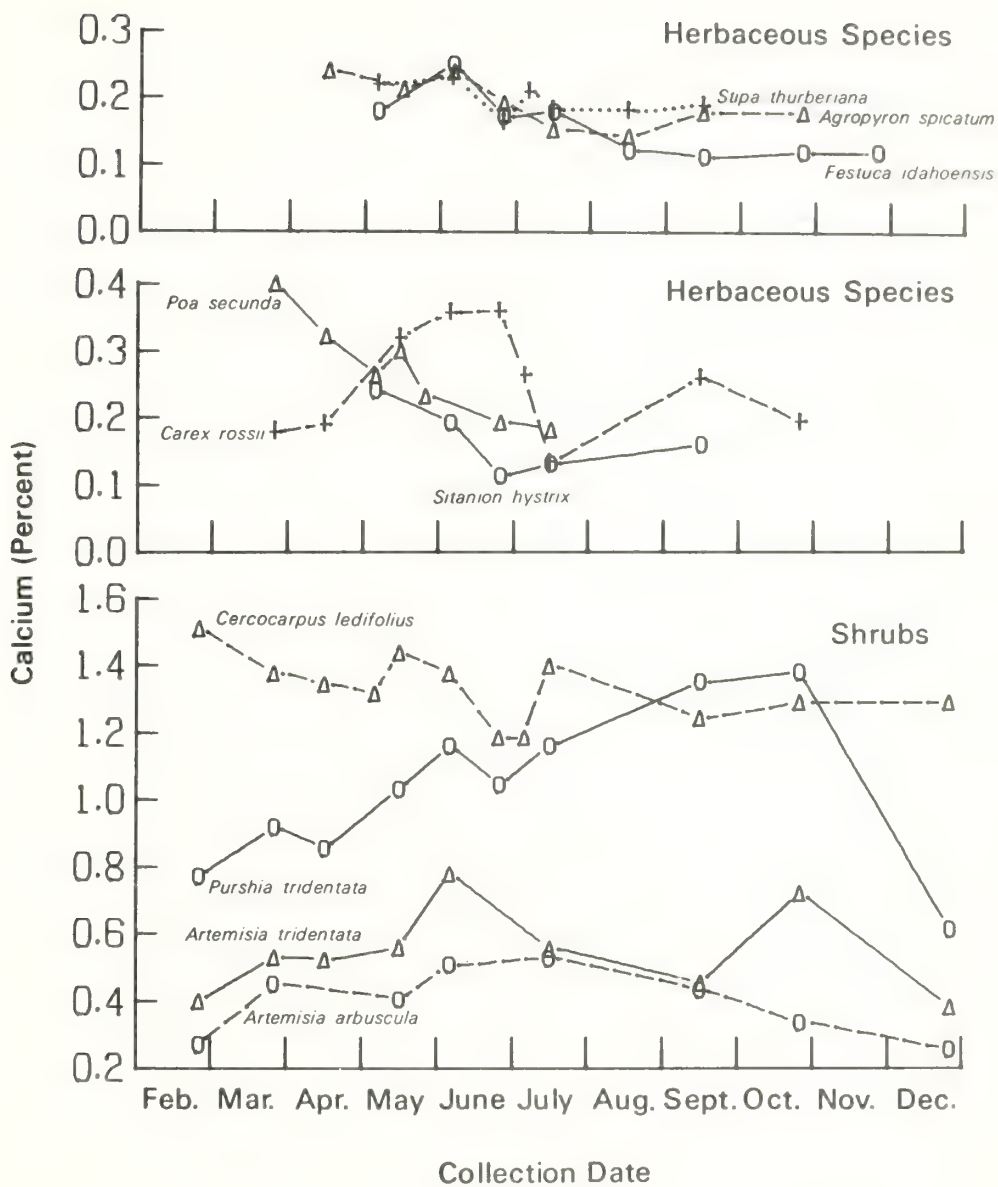


Figure 12.--Seasonal trends of calcium.

calcium. All were higher in calcium than grasses. When compared with shrubs, mountain lily remained intermediate between big sagebrush and bitter brush.

#### PHOSPHORUS

Sandberg bluegrass and bluebunch wheatgrass had the highest spring phosphorus levels among the grasses (fig. 13) but decreased rapidly in these species and dropped below the others by early summer. Ross' sedge had the lowest phosphorus content of species sampled during early spring but increased substantially by mid-May. Idaho fescue had less phosphorus than the other grasses during early spring leaf development but more than Ross' sedge. After boot state (early June), Idaho fescue had the highest phosphorus content of the grasses.

These phosphorus levels are generally lower than grasses studied by Gordon and Sampson (1939) and Skovlin (1967). They are similar to results reported by Whitman et al. (1951).

The shrubs were generally lower in phosphorus than grasses during early spring but higher than the grasses and sedge after midsummer (fig. 13).

During spring, scabland sagebrush was the best shrub source of phosphorus. Big sagebrush contained more phosphorus than the other shrubs throughout the summer, fall, and winter. Bitter brush was the poorest phosphorus source in fall and winter. Mountain mahogany was intermediate and less variable in phosphorus content.

Similar results were obtained by Dietz et al. (1962) for bitter brush, big sagebrush, and Colorado mountain mahogany (*Cercocarpus montanus*) in Colorado and by Smith (1963) for big sagebrush near Silver Lake.

Three forbs were analyzed for phosphorus and were higher than either grasses or shrubs during the period

they were available for sampling.

According to Black et al. (1943), a forage phosphorus content of 0.13 percent is necessary to meet the minimum range cattle requirements. However, the National Research Council (1958) considered forage with less than 0.15 percent phosphorus deficient. Still higher phosphorus levels were recommended by Cook and Harris (1968)--0.17 percent for gestation, 0.22 percent for the first 8 weeks, and 0.20 percent for the last 12 weeks of lactation.

At 0.15 percent, phosphorus became deficient in grasses at dates ranging from early June (Sandberg bluegrass) to mid-August (Idaho fescue) (fig. 13). When related to growth stages, bluebunch wheatgrass became deficient during anthesis, and Idaho fescue and Ross' sedge became deficient soon after seed maturity. Other grasses were intermediate. The forbs were good sources of phosphorus, supplying two to three times the amount required by cattle. Two browse species, mountain mahogany and big sagebrush, supplied adequate phosphorus season long, but bitter brush and scabland sagebrush were deficient in fall.

If 0.20 percent is used, phosphorus becomes deficient about 3 to 4 weeks sooner in the grasses. And, except for the mid-May sample, Ross' sedge is deficient the entire year. All shrubs have ample phosphorus during May and June but become deficient before and after this period.

Regardless of the minimum requirement assumed, the data indicate that phosphorus is likely to be deficient in cattle diets during late summer and fall. Consequently, supplementation may be necessary where this range is used for late season grazing.

Minimum phosphorus requirements have not been determined for deer, but 0.16 percent is minimal for pregnant ewes (Dietz 1965). If deer are similar, grass was deficient in the late spring

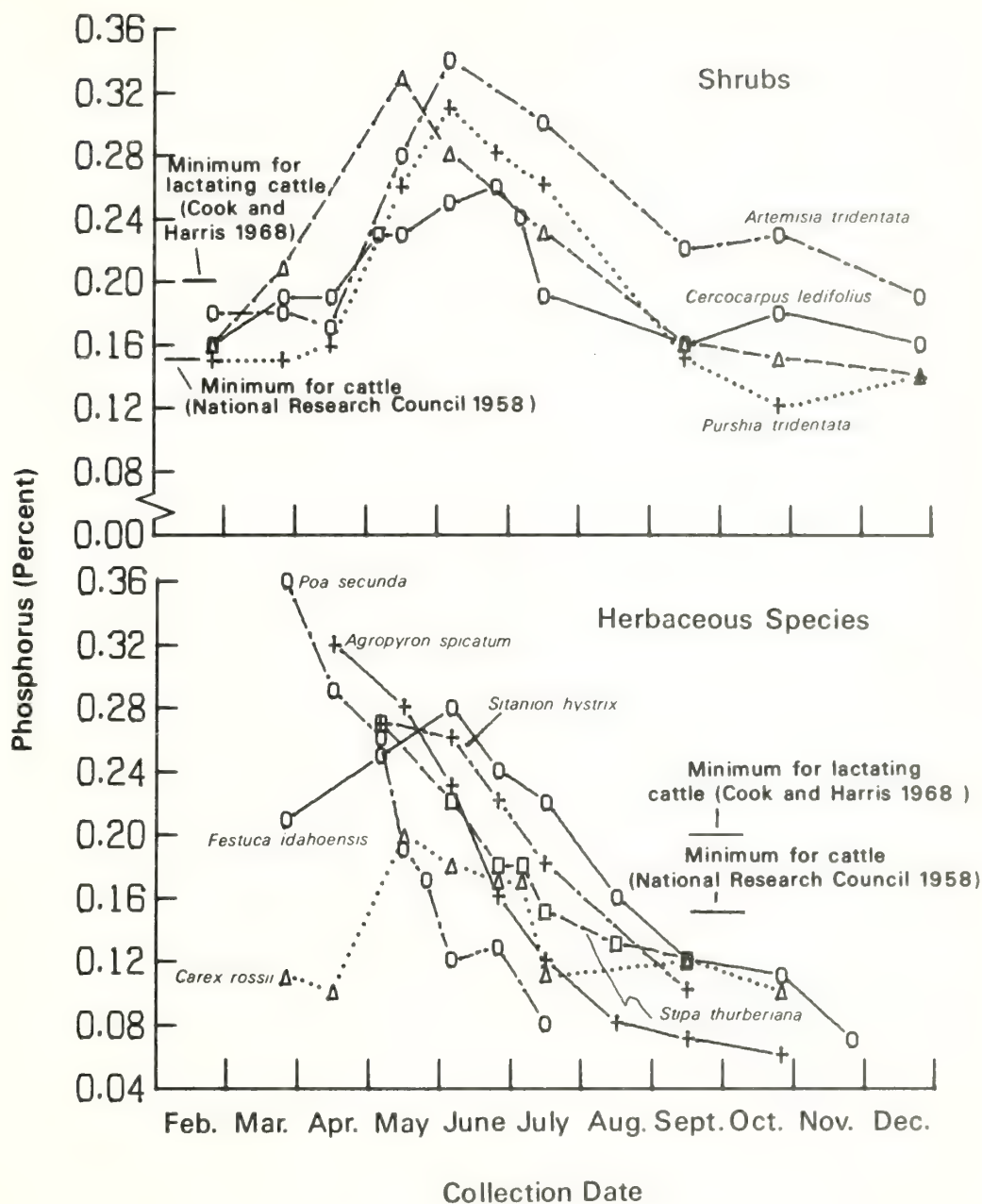


Figure 13.--Seasonal trends of phosphorus.



(Sandberg bluegrass) or summer (all other grasses). Ross' sedge was deficient during the early spring, summer, and fall. Scabland sagebrush and bitter brush were phosphorus deficient during the fall (also winter for bitter brush), while mountain mahogany and big sagebrush were satisfactory throughout the year.

#### CALCIUM:PHOSPHORUS RATIO

The grasses, including Ross' sedge, had calcium:phosphorus ratios between 0.5:1 and 3:1 (fig. 14). Each species, except the sedge, had a ratio near 1:1 early in the season, widening as the season progressed, with greatest increases in Sandberg bluegrass (2:1 by mid-July) and bluebunch wheatgrass (3:1 in October). Little change occurred in Idaho fescue until midfall.

These results differ from those reported by Gordon and Sampson (1939) who found that in California foothill grasses, this ratio (1:1) was constant throughout the season.

Bitter brush and mountain mahogany had ratios wider than those for grasses. Bitter brush ranged from 4:1 to 11:1 and mountain mahogany, from 5:1 to 9:1.

Sagebrushes had little seasonal variation in the ratio compared with bitter brush and mountain mahogany. Ratios were between 1:1 and 3:1, similar to grasses.

Dietz et al. (1962) reported similar ratios for big sagebrush in Colorado (2:1 to 3:1) and found wider values for bitter brush and Colorado mountain mahogany (4:1 to 8:1).

The ratio varied between three forbs. Tall western senecio and Oregon sidalcea ranged between 2:1 and 7:1, while mountain lily remained near 2:1.

According to the recommendation of 0.5:1 to 2:1 as a standard for cattle (Maynard and Loosli 1962),

scabland sagebrush provided the most desirable balance of these minerals in the shrubs. Big sagebrush was slightly higher than this during part of the season. Both mountain mahogany and bitter brush had wider ratios than recommended the entire year. The grasses and sedge were satisfactory most of the season except for the bluebunch wheatgrass during September and October. Mountain lily provided the lowest and most desirable ratio.

#### CRUDE FIBER

Crude fiber varied greatly among herbaceous species during early spring leaf development (fig. 15). Ross' sedge was high in crude fiber in March (26 percent) but lower than the other species later in the season. Although Sandberg bluegrass was earliest in development, it had a curve similar to squirreltail. Both were low in crude fiber in March (14 percent) but had doubled their fiber content by late June.

Thurber needlegrass and Idaho fescue had similar post-July trends but were different earlier. Idaho fescue increased in fiber content at a constant rate throughout the season.

Shrubs (fig. 15) were lower in crude fiber than grasses (except during early spring) as was also reported by Gordon and Sampson (1939). The sagebrushes and mountain mahogany had similar trends--low in midspring and high in the summer and fall (fig. 15). Bitter brush had a different curve that was lowest in summer (anthesis until after seed maturity) and highest in winter.

The forb, mountain lily, contained 12 percent crude fiber; and except for a May sample of scabland sagebrush, it was the lowest in crude fiber of all species.

Dietz et al. (1962) reported similar trends but higher values for crude fiber in bitter brush and scabland sagebrush and a quite different trend for Colorado mountain mahogany,

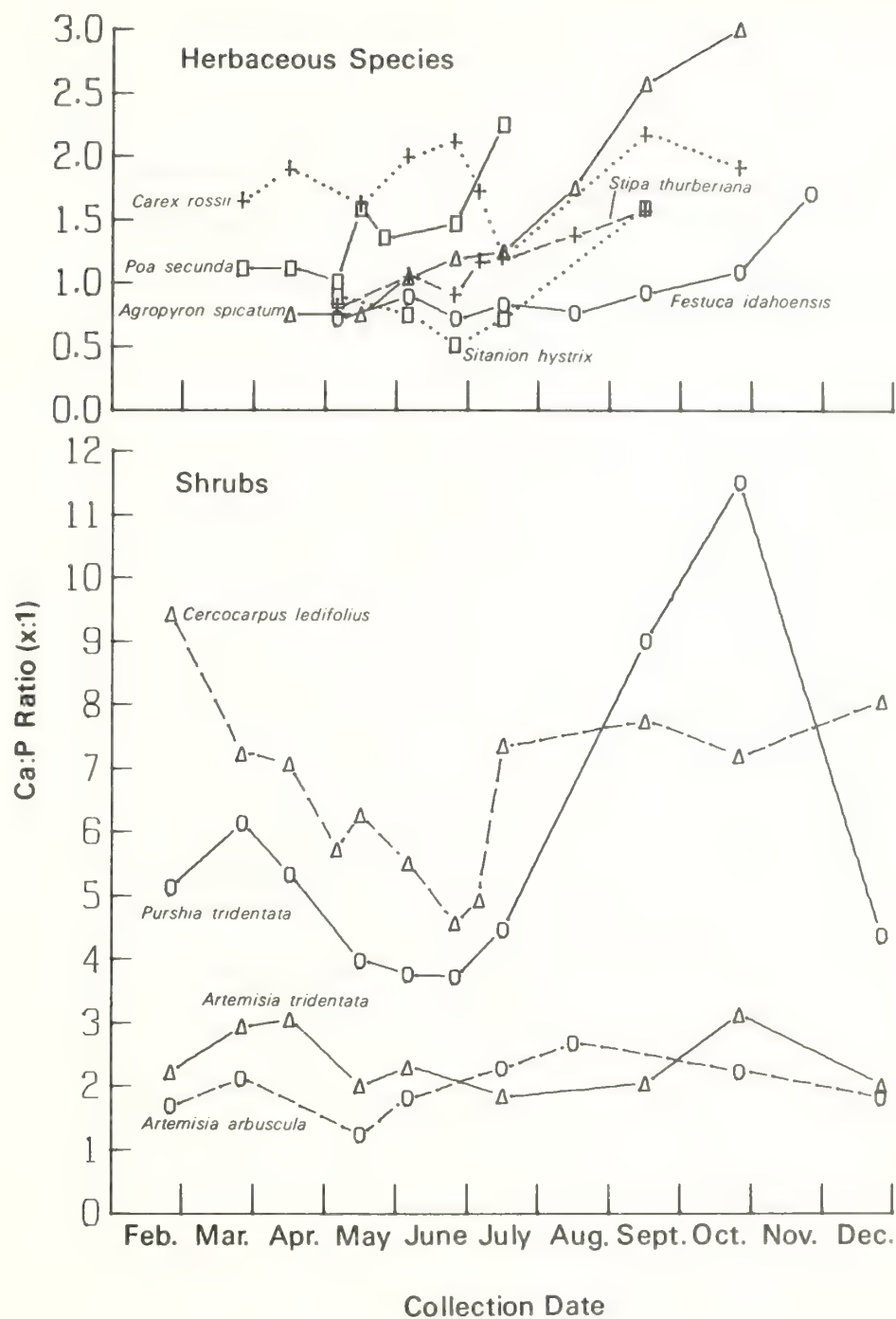


Figure 14.--Seasonal trends of Ca:P ratio.

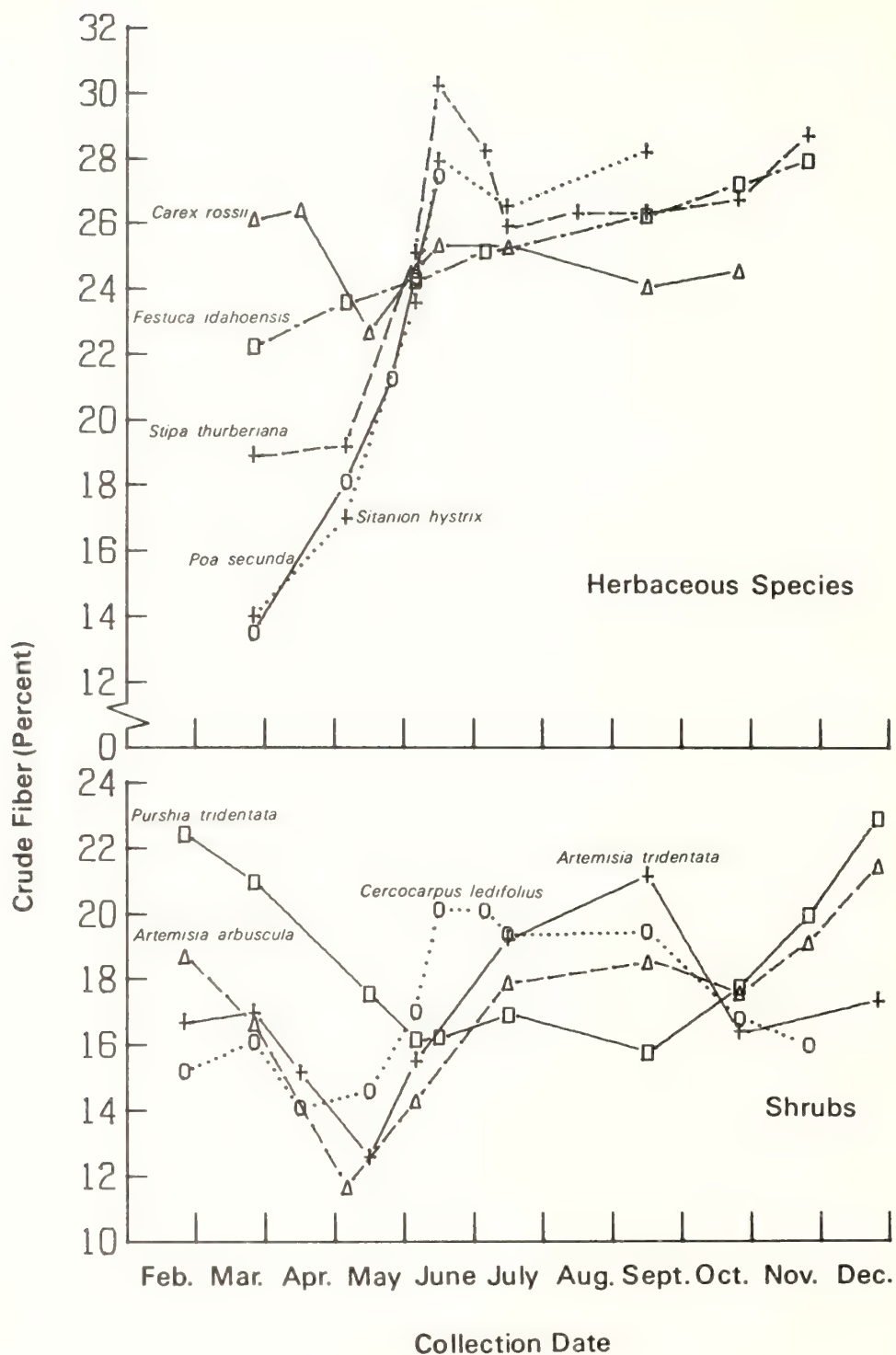


Figure 15.--Seasonal trends of crude fiber.

as well as higher values for *C. ledifolius*. Smith (1963) reported a similar seasonal trend for big sagebrush which was slightly higher than results reported here.

#### CRUDE FAT (ETHER EXTRACT)

The grasses ranged from 1 to 4 percent crude fat (fig. 16). In the early spring needlegrass, squirreltail, and bluegrass were better fat sources than Idaho fescue or Ross' sedge. Crude fat was not determined for bluebunch wheatgrass.

The shrubs were better sources of fat than grasses, especially during winter and early spring when deer are greatly dependent on browse (fig. 16). Big sagebrush was the highest of the shrubs in crude fat during this period. Mountain mahogany was nearly as high and retained a high level of crude fat longer in the spring. Bitter brush generally contained less crude fat than other shrubs.

Dietz et al. (1962) also found bitter brush low in crude fat content and reported 12 to 15 percent crude fat for big sagebrush--much higher than the results reported here. Smith (1963) found seasonal trends for big sagebrush similar to those in this study but reported higher values. The seasonal trend reported here for big sagebrush appears to be accurate but absolute values are unexplainably low.

Crude fat was determined for one forb, mountain lily, and fat content remained between 2 and 4 percent.

#### APPARENT DIGESTIBILITY

Herbaceous species exhibited downward trends in dry matter disappearance (DMD, 24-hour digestion period) during most of the growing season (fig. 17), with absolute values lower than those reported for grasses by Wallace and Raleigh (1962), Wallace et al. (1965), and Pearson (1964).

Grasses (except for Idaho fescue) were highly digestible early in the season (44- to 67-percent DMD) but decreased to values less than 30 percent. Idaho fescue was low in digestibility (30 percent) at the earliest collection date. In the fall, it was higher in digestibility than other grasses. Sandberg bluegrass dropped more rapidly in DMD than other grasses, but this was related to its short growth period and early maturity. Ross' sedge, although less digestible than most grasses in the spring, remained well above 40-percent DMD at the summer and fall collections. This may be related to its tendency to remain succulent while the grasses mature and dry.

The shrubs had less seasonal variation in apparent digestibility than most herbaceous species (fig. 17). They were less digestible than most grasses early in the season but higher than grasses late in the season. Big sagebrush was consistently higher in DMD than other shrubs and was closely paralleled by scabland sagebrush at a lower level. Mountain mahogany and bitter brush had more variation in DMD with growth stage than did the sagebrush species. During late spring and summer, mountain mahogany was the lowest shrub in digestibility; and during the winter and early spring, bitter brush was least digestible.

Only two forbs were studied. Both were very high in DMD (57 to 73 percent) during the short period they were sampled.

Digestibility was also determined with a 48-hour digestion period for two species, bitter brush and Idaho fescue. When compared with the 24-hour digestion period there was a sizable increase in DMD for the grass, but only a small increase (except in October) for the shrub. Wallace et al. (1965) reported that, for meadow and rye hay, digestibility by sheep was underestimated by the 24-hour period and overestimated by the 48-hour period, suggesting that the best approximation would be intermediate.

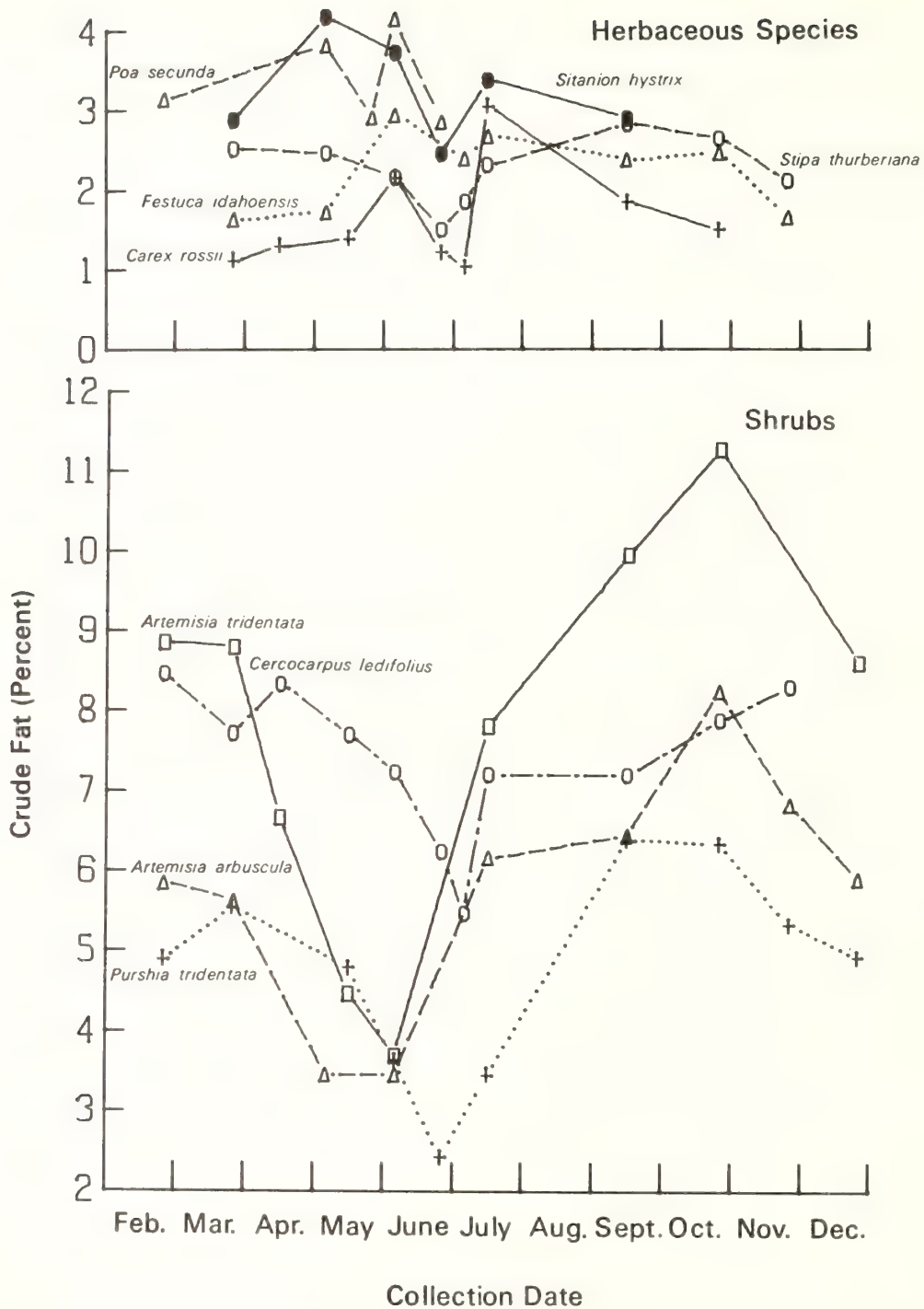


Figure 16.--Seasonal trends of crude fat.



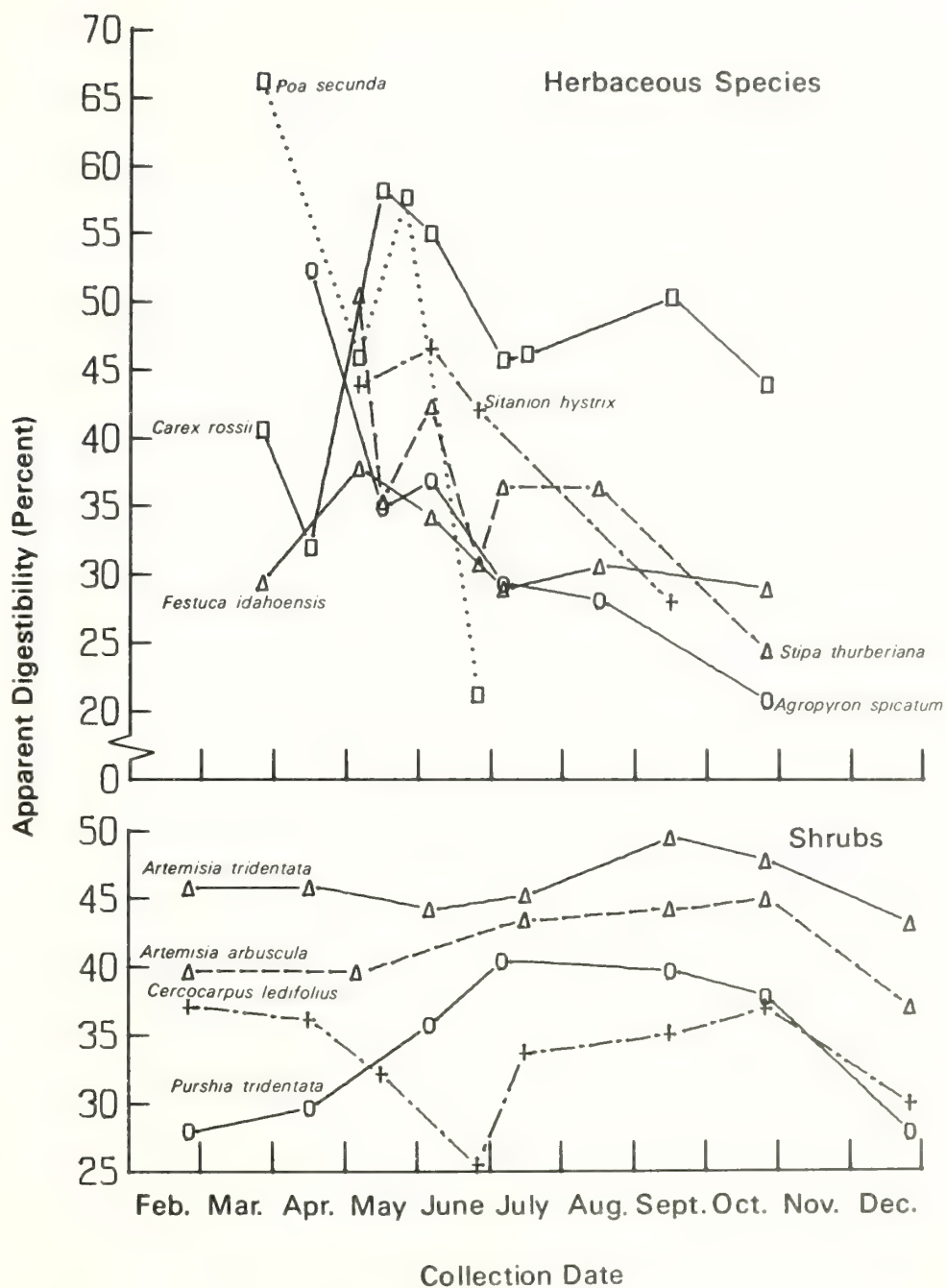


Figure 17.--Seasonal trends of apparent digestibility (24-hour digestion period).

Because these data were obtained using rumen juice from a steer, it is not known whether the results are directly applicable to deer.

## The Effect of Site on Chemical Composition

Chemical composition varied with the site or vegetation type from which the species was collected. Some differences might be attributed to the sampling vagaries. However, some variation was the result of differences in the growth stages of plants sampled in the various types.

Other factors can also contribute to such differences. Cook and Harris (1950b) attributed the change in plant composition by sites to differences in shade and soil moisture. Also, the soil character may affect plant absorption and vegetative composition (Richardson et al. 1954). Nutrient content depends, within limits, on interaction between chemical, physical, and biological factors associated with the environment.

The apparent effects of site on chemical composition are summarized for those constituents which had consistent seasonal differences between sites. These differences cannot be substantiated statistically because of the lack of replicates.

IDAHO FESCUE (*Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis*; *Purshia tridentata*/*Festuca idahoensis*; *Juniperus occidentalis*/*Festuca idahoensis*)

Crude protein was consistently higher in Idaho fescue growing in the *Purshia tridentata*/*Festuca idahoensis* type than in the *Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis* or *Juniperus occidentalis*/*Festuca idahoensis* types during May through September. Ash was highest in the *Purshia tridentata*/*Festuca idahoensis* type and lowest in the *Juniperus occidentalis*/*Festuca idahoensis* type from

July until the end of the season. Crude fat content of Idaho fescue was highest in the *Purshia tridentata*/*Festuca idahoensis* type throughout the season. Except for one sampling date, crude fat remained the lowest in the *Juniperus occidentalis*/*Festuca idahoensis* type.

SQUIRRELTAIL (*Purshia tridentata*-*Artemisia arbuscula*/*Poa secunda*; *Artemisia arbuscula*/*Poa secunda*)

Phenological development of squirreltail was 2 weeks earlier in *Artemisia arbuscula*/*Poa secunda* than the *Purshia tridentata*-*Artemisia arbuscula*/*Poa secunda* type. Squirreltail plants were also small and stunted in *Artemisia arbuscula*/*Poa secunda* type but large and vigorous in the *Purshia tridentata*-*Artemisia arbuscula*/*Poa secunda* type. The data reflected the differences in growth stages for nearly all constituents.

Moisture, crude protein, crude fat, and phosphorus contents of squirreltail were consistently higher in the *Purshia tridentata*-*Artemisia arbuscula*/*Poa secunda* type at all sampling dates. Crude fiber was also higher in the *Purshia tridentata*-*Artemisia arbuscula*/*Poa secunda* type after mid-June. Except for one sample date, ash content remained higher in squirreltail collected from the *Artemisia arbuscula*/*Poa secunda* type.

BITTER BRUSH (*Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis*; *Purshia tridentata*/*Festuca idahoensis*)

Ash and calcium were consistently higher in bitter brush collected from *Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis* than from the *Purshia tridentata*/*Festuca idahoensis* type. Except for the spring period, phosphorus content was also higher in the *Pinus ponderosa*/*Purshia tridentata*/*Festuca idahoensis* type. Crude fiber was much higher in bitter brush from

the *Pinus ponderosa*/*Purshia tridentata*/  
*Festuca idahoensis* type from May  
through October.

## SUMMARY

Seasonal nutrient trends were determined for several prominent grasses, forbs, and shrubs found in a portion of the Silver Lake winter deer range about 80 miles south of Bend, Oregon. Sampling included one complete annual growth cycle for most species. Composite samples (each observation) were collected from within particular vegetation types, and the average growth stage was estimated for each sample. Laboratory analyses were made for moisture, crude protein, ash, calcium, phosphorus, crude fiber, crude fat (ether extract), and apparent digestibility (dry matter disappearance).

In the grasses, calcium, phosphorus, crude protein, apparent digestibility, and moisture generally declined as the season progressed. Crude fiber and ash content increased with plant maturity. Crude fat had no distinct trend that was related to plant development. The calcium:phosphorus ratio widened in most species as the season progressed.

Seasonal trends for phosphorus, ash, crude protein, and moisture appear to be associated in all the shrubs studied. These constituents reached a peak during the spring and a low point in the fall or winter. Unlike in the grasses, crude fat in the shrubs had a distinct seasonal trend. This trend appeared to be inversely related to moisture content. Calcium, apparent digestibility, and crude fiber trends varied considerably among species.

The number of forb samples was inadequate to make positive statements about seasonal nutrient trends in these species. However, both moisture and apparent digestibility were high in forbs during the sampling period. The calcium:phosphorus ratio appeared to widen with plant maturity, whereas moisture, crude protein, and apparent digestibility tended to decrease.

The effect of site (vegetation type) on chemical composition was studied in bitter brush, Idaho fescue, and squirreltail. Probable differences between sites, found for several constituents, are considered to be the result of growth stage differences, shading, or other factors associated with the various environments sampled.

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Moisture, crude protein, ash, calcium, phosphorus, calcium:phosphorus ratios, crude fiber, crude fat, and apparent digestibility were determined for 15 species in three vegetal classes on seven vegetation types. These measurements were contrasted by classes, species, and type, and ungulate management inferences were drawn.

KEYWORDS: Nutrient regime (animal), range production, forage plants.

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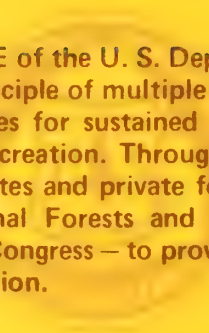
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USDA Forest Service  
Research Paper PNW-188  
1975



# Geology and Geomorphology of the H.J. Andrews Experimental Forest, Western Cascades, Oregon

Frederick J. Swanson  
and Michael E. James

Pacific Northwest Forest and Range Experiment Station  
Forest Service, U. S. Department of Agriculture  
Portland, Oregon

## ABSTRACT

At low and middle elevations in the H. J. Andrews Experimental Forest, the bedrock geology is comprised of Little Butte Formation altered volcaniclastic rocks, predominantly of ash flow and mudflow origin. This unit is overlain by upper Miocene and Pliocene lava flows which contain some interbeds of pyroclastic and fluvial material.

The present landscape has been formed during approximately the past 4 million years by fluvial, glacial, and mass movement processes. Both shallow and deep-seated mass movements tend to occur in the relatively unstable rocks of the Little Butte Formation and especially in the contact zone where lava flows cap unstable volcaniclastic rocks.

The close link between bedrock geology and mass movements should be useful in forest management decisions concerned with lands in the Western Cascades.

Keywords: Experimental Forest management plans, geology, soil management (forest).

## ACKNOWLEDGMENTS

This study was supported by National Science Foundation grant GB-36810X to the Coniferous Forest Biome, U.S. Analysis of Ecosystems, International Biological Program. U.S. Forest Service Research Work Unit PNW 1602 generously supplied equipment and facilities for this study. During the course of the work C. T. Dyrness, R. L. Fredriksen, D. N. Swanston (all of the Pacific Northwest Forest and Range Experiment Station), and R. B. Parsons (Soil Conservation Service) contributed many helpful ideas and critical discussions concerning the area. This is contribution number 120 from the Coniferous Forest Biome.

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## INTRODUCTION

In many areas of mountainous country, the development and productivity of forest ecosystems are closely linked with the geologic and geomorphic processes acting on the landscape. This is particularly true in areas such as the western Cascades of Oregon where erosion rates are naturally high, and deep-seated and shallow mass movements occur frequently. Furthermore, studies by Anderson (1954), Dyrness (1967), Fredriksen (1970), and others indicate that land management activities may substantially increase erosion, especially by road-related shallow soil mass movements. Increased fundamental knowledge of erosional processes is a prerequisite for sound management of unstable lands.

For this reason the U. S. Forest Service and the Coniferous Forest Biome of the International Biological Program have undertaken geology and geomorphology studies in the H. J. Andrews Experimental Forest in the western Cascade Range about 50 miles (80 km) east of Eugene, Oregon. The purpose of the work has been to collect information on bedrock and surficial geology which can be integrated with more detailed studies of erosion, soil genesis, and nutrient cycling. This paper summarizes the geologic and geomorphic histories of the Forest area and emphasizes the relationships between bedrock geology and mass wasting events.

## GEOLOGY OF THE H. J. ANDREWS EXPERIMENTAL FOREST

A stratigraphic column and generalized bedrock geology map of the area are shown in figure 1. The Lookout Creek drainage which makes up the Forest is underlain exclusively by rocks of volcanic origin, including lava flows, ash flows,

air fall tuffs, cinder beds, and water-worked tuffaceous sediments.

In this report, rock units are grouped following the designations used by Peck et al. (1964), who dated formations on the basis of paleobotany. A current project for potassium-argon dating of Cascade rocks (Dr. A. R. McBirney, University of Oregon, personal communication, 1974) may result in some major revisions in the stratigraphy and accepted ages of Western Cascade rock units.

The oldest rocks are included in the Oligocene to lower Miocene Little Butte Formation (fig. 1). The base of the section exposed in the Forest is located at the mouth of Lookout Creek. The rocks consist of massive, green, blocky breccias derived from mudflows and pumice-deficient pyroclastic flows. Higher in the section, pumice-bearing welded and nonwelded ash flows are dominant rock units. In several places within the section there are abundant waterworked volcanic sediments.

At several locations between 2,000-foot (610-m) and 2,500-foot (760-m) elevation, there are exposures of basaltic flow rock, often containing green mineralization and silica precipitated in fractures. The limited lateral extent of the flows suggests that they occurred as intercanion flows over a stream-dissected landscape. A further indication of significant topographic relief during late Little Butte time is the presence of several hundred feet (about 100 m) of tuffaceous siltstone and sandstone which accumulated with some plant matter in small lake basins (mapped in fig. 1).

In the western part of the mapped area, several dozen vertical dikes, ranging in composition from basalt to rhyolite, cut through the volcanoclastic country rock in a consistently northwesterly trend. The dikes appear to have served as local



UPPER MIOCENE: UPPER MIOCENE, MIDDLE AND LOWER MIOCENE

- EXTRUSIVE ROCK**
- 15' PABF
  - 15' PS
  - "PLOCASCADE" VOLCANICS
  - PBP
  - PSAF
- SARDINE FORMATION**
- SABF
  - SWABF
  - SAFT
- LITTLE BUTTE FORMATION**
- LBTS
  - LBBF
  - LBVPS
- INTRUSIVE ROCK**
- Basaltic and rhyolitic dikes, dashed where inferred
- MAP SYMBOLS**
- Strike and dip
  - Contact (observed, inferred, obscured by mass movement)
  - Fault with relative up (U) and down (D) displacement
  - Roads
  - 500-foot contour lines
  - Drainage systems

# GEOLOGIC MAP LEGEND

- Andesitic and basaltic lava flows
- Fluvial and lacustrine silt, sand, and gravel
- Basaltic pyroclastic rocks
- Subaqueous lava flows
- Andesitic and basaltic lava flows
- Altered and weathered, mass movement prone, flow rock capped tuff
- Ash flow tuffs, welded and nonwelded, alteration minor
- Tuffaceous silt and sand lacustrine sediments
- Basaltic flows
- Volcaniclastic rocks--mudflow, welded and nonwelded pyroclastic flows, air fall tuff, water-worked volcanic sediments, zones of propylitic and zeolitic alteration
- Basaltic and rhyolitic dikes, dashed where inferred

10'

122° 07' 30"

CARPENTER MTN

PBP

SABF

SAFT

PABF

SAFT

SABF

SAFT

PBP

-44° 13' 30"

FRISSELL POINT

LOOKOUT MTN

SWABF

SABF

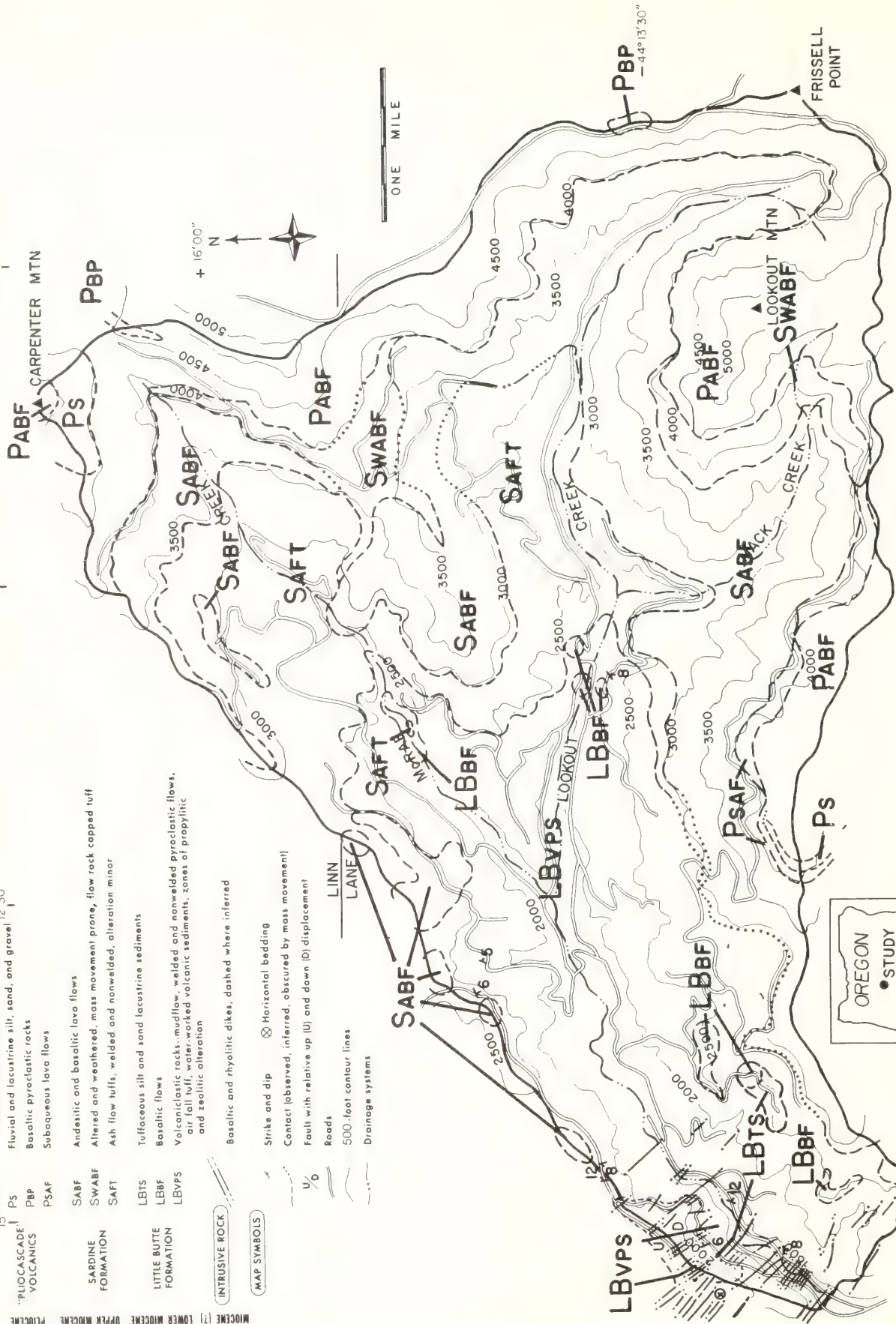
PABF

PS

OREGON STUDY AREA

ONE MILE

+ 16' 00"



feeders for some of the ash flows and lava flows of the Little Butte and the overlying Sardine Formations.

Capping the Little Butte clastic and flow rocks are two units of the Sardine Formation, dated as middle- to late-Miocene by Peck et al. (1964). The Little Butte-Sardine contact, though difficult to trace through the forest cover, varies in elevation from about 2,500 to 3,000 feet (760 to 915 m), indicating that there was more than 500 feet (150 m) of relief on the pre-Sardine landscape. The lower Sardine unit contains welded and nonwelded ash flows which are notably less altered than underlying rocks of similar lithology mapped as Little Butte. Basalt and andesite lava flows make up the bulk of the upper Sardine unit. The contact between the units is complicated by the interstratification of lava flows and ash flows.

In several locations the uppermost Sardine age flows appear to have been deeply weathered during a long hiatus before eruptive activity began again.

Andesitic and basaltic lava flows, cinder beds, and sediments which overlie the Sardine have been informally designated "Pliocascade" by Dr. E. M. Taylor (Oregon State University, personal communication, 1973). In the Forest area, Pliocene volcanism commenced with pyroclastic eruptions in the vicinity of Lookout Mountain and Frissell Point. Several distinct cinder cones were constructed and possibly served as vents for lavas which flowed to the north and west. In the area of what is now Lookout Ridge, lavas flowed westward into a lake or partially dammed river system, resulting in the formation of pillow lavas and amber-colored, glassy breccias produced by quenching. Some fluvial and lacustrine sediments are interbedded with the flows.

Several flows within the "Pliocascade" sequence have been dated by potassium-argon methods at  $6.1 \pm 0.1$  and  $3.9 \pm 0.1$  million years in age (E. M. Taylor, Oregon State University, personal communication, and A. R. McBirney, University of Oregon, personal communication, 1974). Since that time the area of the present High Cascade Mountains immediately east of the Forest was downdropped along a series of north-south trending, high angle normal faults. Displacement took place in a zone of parallel, north-south faults which extends from Frissell Point eastward to the McKenzie River where it disappears beneath the cover of younger High Cascade lavas. When High Cascade volcanism began about 2.0 to 2.5 million years ago (E. M. Taylor, Oregon State University, personal communication), the Forest area had been sufficiently uplifted that no High Cascade lava flows spilled into the Lookout Creek drainage.

## GEOMORPHOLOGY OF THE H. J. ANDREWS EXPERIMENTAL FOREST

Geomorphic development of the modern Lookout Creek drainage probably began about 4 million years ago, during the close of Pliocene volcanic activity. River gravel and quiet water sediments beneath "Pliocascade" lavas near the tops of Lookout Ridge and Carpenter Mountain indicate that the early and middle Pliocene geography bore little resemblance to the modern landscape. Late Pliocene volcanism flooded the pre-"Pliocascade" landscape, filling in stream valleys and essentially setting the stage for development of the Lookout Creek drainage during Quaternary time.

Glacial, fluvial, and mass wasting



processes have all had important roles in shaping the present morphology of Lookout Creek valley. Rapid erosion of the steep terrain has erased much of the record of the early geomorphic history of the area. However, landforms and surficial deposits which date back as much as several tens of thousands of years leave a clear record of recent actions of glacial, alluvial, and mass movement processes in the valley.

We will first briefly summarize the glacial and fluvial histories of the area and then describe mass movement processes, which deserve special emphasis from the viewpoint of land management.

## Glacial History

Numerous landforms and surficial deposits record a history of glaciation within the Forest. Cirques were developed on north and northeast aspects where ridges exceed about 4,500 feet (1,370 m) in elevation. The flatter parts of the cirque floors are covered with patches of compacted till which is probably of latest Wisconsin age. This estimate is based on the oxidation of the deposits to a depth of less than 3 feet (1 m), which is comparable with the weathering of latest Wisconsin till identified in the McKenzie River valley by Taylor (1968). More extensive, pre-latest Wisconsin till and fluvioglacial outwash are recognized by greater depths of weathering. Remnants of these deposits occur along Lookout Creek to a point at least 0.6 mile (1 km) below its confluence with Mack Creek and down McRae Creek valley to an elevation of about 2,500 feet (760 m). The preserved glacial material has a patchy distribution as a result of erosion from hill-slope areas and fluvial reworking along the valley floor.

There are also indications that

movement of glaciers into the mouth of Blue River formed an ice-dammed lake which flooded the lower kilometer of the Lookout Creek valley. Swanson and James interpret exposures of fine-grained, lacustrine sediments in the banks of lower Blue River and Lookout Creek as having accumulated in such a depositional environment.

## Alluvial History

Fluvial processes have constructed terraces and numerous small alluvial fans along the valley bottoms of Lookout Creek and some of its major tributaries. Geomorphic units forming the valley floor along the lower 2-1/2 miles (4 km) of Lookout Creek include the modern channel, a vegetated flood plain, and a terrace surface 15 to 25 feet (5 to 8 m) above the active channel. In places on the terrace surface there are patches of volcanic ash from the eruption of Mount Mazama (correlation based on petrographic characteristics). Wood fragments associated with the ash have been dated by radiocarbon methods at about 7,000 years before present (b.p.) (Kittleman 1973). This indicates that the terrace surface had been abandoned as a flood plain by that time, and since then Lookout Creek has been actively down-cutting. In addition, alluvial fans have been constructed onto the terrace surface from the mouths of tributary streams beginning more than 7,000 years b.p. (Swanson and James (1975) present a detailed discussion of fan and terrace stratigraphy.)

At a point about 3 miles (5 km) upstream from the mouth of Lookout Creek, the character of landforms on the valley floor changes markedly. Downstream the valley bottom is narrow, generally 300 to 1,000 feet (90 to 305 m) wide, and the terrace is a prominent landform. Upstream to a point about half a mile (1 km) below

Mack Creek, alluvial deposits extend from 1,000 to 1,300 feet (305 to 395 m) across the valley floor and have a definite asymmetry with thickest deposits occurring on the south side.

Two factors account for the contrasting characteristics of the upstream and downstream valley segments. The point of transition is located at the base of a massive earthflow (shown in figures 2 and 3), which has raised local baselevel by dumping large quantities of sediment into the stream. Consequently, the upstream portion of the Lookout Creek aggraded, constructing a broad flood plain. In addition, greater influx of sediment from the large tributary watersheds on the south side of the valley resulted in formation of a wedge of sedimentary deposits along the southern margin of the valley.

The history of these landforms began with alluviation of the valley in response to glacial and mass movement processes operating in the large watersheds on the north face of Lookout Ridge. Most of this sedimentation occurred during latest Wisconsin deglaciation and earlier, probably more than 10,000 years b.p. Subsequently, Lookout Creek began to exhume its channel, and in places the stream has now cut down through as much as 60 feet (20 m) of the fill. This transition from aggradational to degradational fluvial regimens in early to middle Holocene time has also been documented in lower Blue River (see footnote 1) and in the Willamette Valley (Balster and Parsons 1968).

The timing of movement of the massive earthflow is difficult to determine. Mazama ash was collected in some closed depressions on the landslide terrain, indicating that the mass movement topography had begun to develop more

than 7,000 years b.p. However, the steep, actively eroding, 130-foot-high (40-m-high) cliffs at the toe of the earthflow (location "X" on figure 2) and the shallowness of stream incision on the earthflow terrain suggest that movement has probably continued until quite recently and portions of the area may still be active today.

Another example of the interaction of earthflows and streams is discussed in the following section and sketched in figure 4. These situations emphasize the close interrelationships among fluvial, mass movement, and glacial processes.

## Deep-Seated Mass Movement History

Massive, deep-seated earth failures have had an important part in forming the present Lookout Creek landscape. Most of the landslide areas mapped in the Forest (fig. 2) may be classed as slump-earthflow types (Varnes 1958). Such events involve the simple downward sliding of massive slices or blocks of material in the upper part of a failure zone; in the lower portion of the moving mass, transport takes place mainly by a flowage mechanism. Some of the smaller failures are rotational slumps in which the failing mass rotates on a curved sliding surface with only minor disruption of the moving block.

Slump-earthflow areas and simple rotational slumps were identified in the field and aerial photographs on the basis of three groups of criteria: (1) large-scale topographic features such as anomalous drainage patterns; (2) small-scale topographic features, mainly hummocky ground, scarps, and poorly drained depressions; and (3) vegetation disturbed by ground movement.

In some of the larger areas of earthflow activity (greater than several hundred



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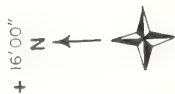
15'

CARPENTER MTN

- ROADS
- 500-FOOT CONTOUR LINES
- DRAINAGE SYSTEMS
- INACTIVE ROTATIONAL SLUMPS
- ACTIVE } SLUMP → EARTHFLOW
- INACTIVE }
- HEADWALL SCARP
- SLIDE MATERIAL

LINN  
LANE

ONE  
MILE



-44° 13' 30"

FRISSELL  
POINT

LOOKOUT  
MTN

MACK  
CREEK

GREEN  
CREEK

LOOKOUT

MCRAE

OREGON  
● STUDY  
AREA



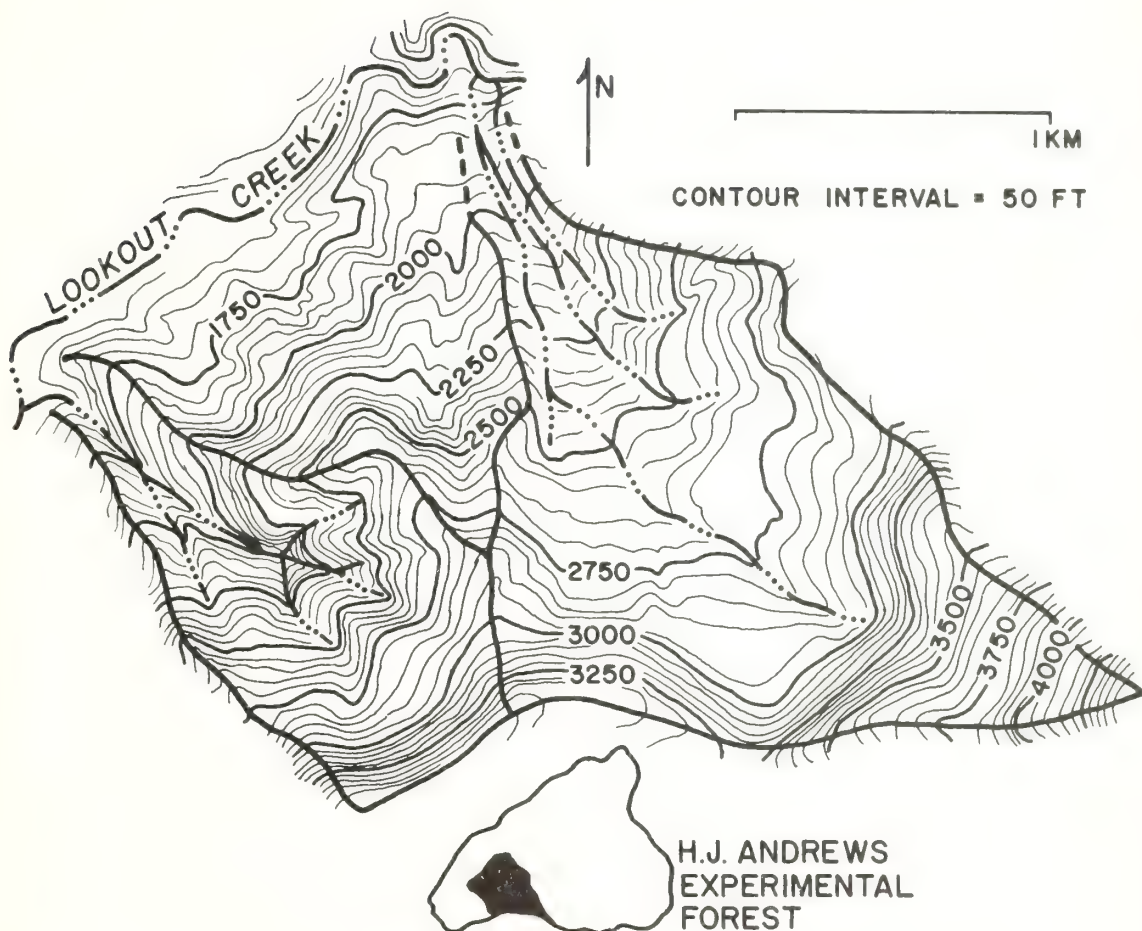


Figure 3.--Topographic map showing contrasting topography between experimental watershed #3 (Fredriksen 1970) on left, which has been deeply dissected by stream erosion and the watershed on right which has undergone deep-seated failure, filling the lower part of the drainage with mass movement material.

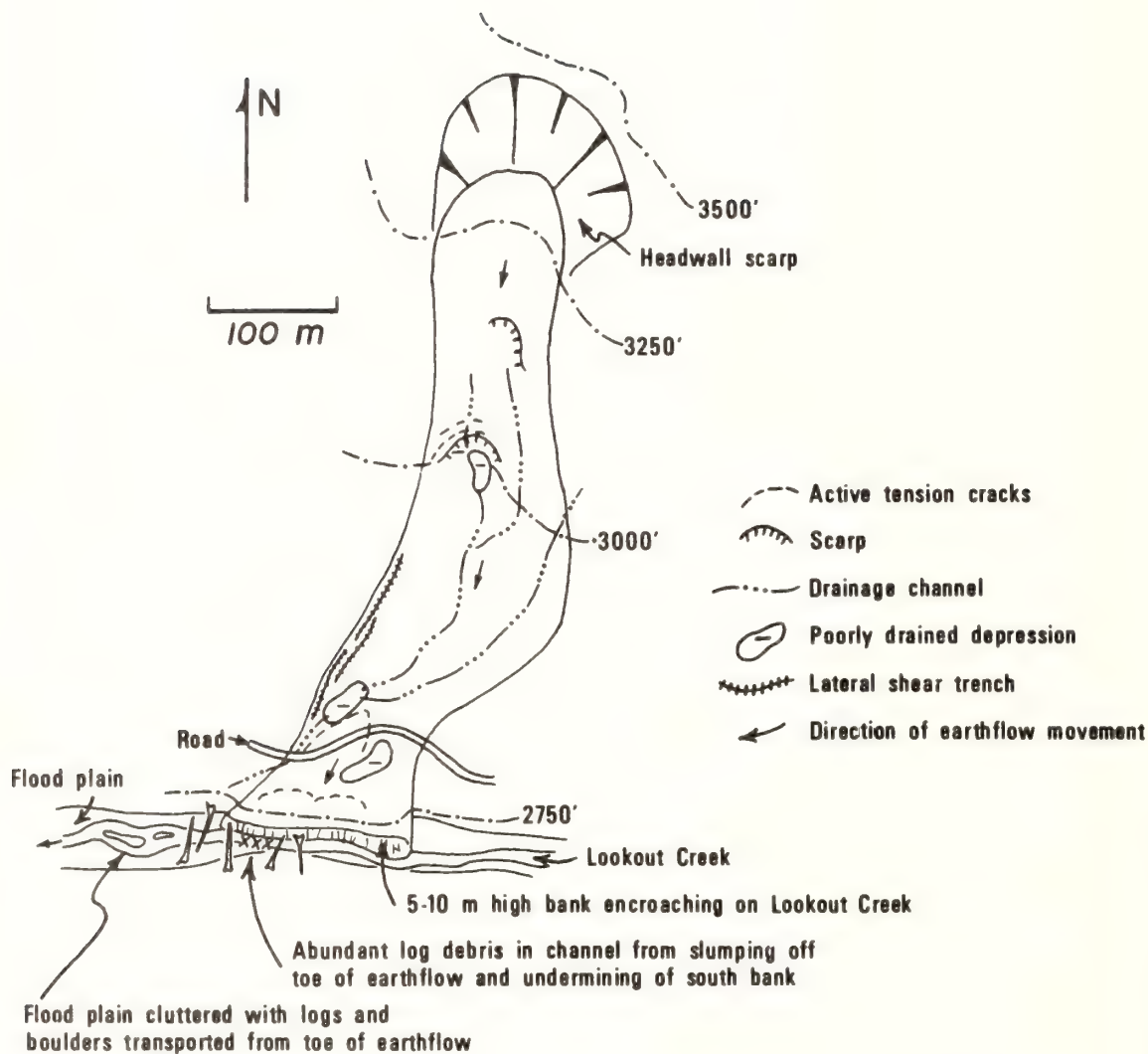


Figure 4.--Sketch map of active slump-earthflow (location "Y" in figure 2), showing surface features and impact on Lookout Creek.

acres or about 100 ha), earth movement has produced large, bowl-shaped drainages; hummocky topography in the central and lower portions of watersheds; poorly developed drainage systems, including sets of small parallel streams; and temporary blockage or diversion of the main-stream channel at the foot of the watershed. All of these features are observed in the watershed shown in figure 3. The distinctive characteristics of the disrupted watershed are especially evident when contrasted with the adjacent, deeply incised drainage to the west. Practically the entire area of the watershed on the east has undergone massive deep-seated earthflow, creating a steep headwall scarp across the top of the drainage and completely burying and reshaping the former topography of the lower 70 percent of the basin below an elevation of 3,000 feet (915 m).

Zaruba and Mencl (1969), Varnes (1958), and others offer excellent descriptions of the smaller scale surface characteristics of mass movement areas. The most common features in the study area include poorly drained depressions (ponds or skunk cabbage (*Lysichitum americanum*) and cedar (*Thuja plicata*) bogs); arcuate, concave downslope scarps, and hummocky topography. Figure 4 shows examples of surface morphological features on an active earthflow encroaching on a section of Lookout Creek.

The character of vegetation also is an excellent indication of active earth movement at unstable sites. The presence of "jackstrawed," or tipped and bowed, trees is commonly interpreted as the result of land movement churning the ground and tilting of trees on the ground surface. However, it is necessary to use care in vegetation study because trees may also have irregular growth form resulting from snow creep, change

in canopy structure due to blowdown, wind tilting, other trees falling or rolling against them, and other factors. In analysis of vegetation it is also important to note that some species tend to be more stable than others; e.g., Douglas-fir (*Pseudotsuga menziesii*) is more windfirm than western redcedar (*Thuja plicata*). Some stands have mixed growth forms with older trees (greater than 200 years in age) being "jackstrawed," while intermixed younger timber (less than 100 years old, for example) is not. These circumstances may result from a period of recent stability or from earth movement so slow that tree form is affected only on the longer time scale.

For presently inactive mass movement areas, four criteria may be used to estimate the time elapsed since the last substantial movement took place: (1) the landforms which define the movement area are extensively dissected by postslide erosion, (2) slide material is overlain by glacial deposits showing no indication of having been moved by the slide, (3) slightly reworked beds of Mazama ash have collected in closed depressions on a slide topography which is pre-ash in age, and (4) the vegetation shows no sign of having been bowed and tilted by earth movement. These criteria are ranked in order of decreasing minimum time period of stability, ranging from several tens of thousands of years for criterion 1 to several centuries for criterion 4. Mass movement areas noted as "Active" in figure 2 exhibit tilted and bowed trees and in some cases freshly exposed slippage planes.

The rates of earthflow movements in the western Cascades have not been documented in any detail. However, preliminary observation suggests that movement rates vary from zero in presently stable areas to more than 1 yard per year (1 m/yr) for very active flows. The higher rates have been registered by downslope



movement of segments of roads and the encroachment of flows over roads.

As slow-moving, deep-seated failure takes place, there is a general decrease in relief over the surface of the sliding mass. This results in increased stability until a stable configuration is reached and movement slows or stops. Movement may start again during later periods of very heavy precipitation either as single storms or as long-term changes in precipitation patterns over several years. Movement may also be reactivated by changes in distribution of mass in the failure area due to the single or combined effects of road construction, stream erosion, or small-scale mass movements. These processes account for some of the complexity of earthflow terrains which include both presently active and long stable areas, e.g., the very large mass movement area in the east-central portion of figure 2.

Comparison of figures 1 and 2 demonstrates the strong control which bedrock geology has on deep-seated mass movements. The principal failure zone of many of the failures, especially the larger ones, is near the contact where lava flows and welded ash flow beds cap volcanoclastic rock. In fact, much of the length of the contact zone in the west half of Lookout Ridge lies along the headwalls of mappable mass movement areas. In higher elevation areas underlain exclusively by lava flows, there is no evidence of extensive mass movement. Below the contact zone there are a few small, scattered, deep-seated failures which occur entirely within volcanoclastic bedrock.

The tendency for landslides to have headwall scarps at the contact zone is related to the capping effect of the flow rocks in the headwaters of small watersheds. The underlying volcanoclastic

rocks are much more susceptible to erosion by mass soil movements (Dyrness 1967) and stream cutting. The greater resistance of the capping flow rocks to these erosional processes prevents the establishment of a stable slope profile. In moist, temperate regions these circumstances commonly result in the development of deep-seated rotational slumps and earthflows.

## Shallow Soil Mass Movement History

In this study, as in Dyrness (1967), shallow soil mass movements are classed as those events in which more than 100 cubic yards (76 m<sup>3</sup>) of mainly soil, colluvial, and, possibly, vegetative material is transported rapidly downslope. From a land management viewpoint these events pose the major erosion problem in the western Cascades. Shallow mass wasting damages roads, removes soil from tree-growing sites, and may lead to degradation of water quality and the stream habitat.

Dyrness (1967) offers an excellent description of the types and occurrences of 47 shallow mass movements which took place in the Forest as a result of severe storms in December 1964 and January 1965. The recorded events include slumps, small earthflows, debris slides, avalanches, and torrents. Dyrness observed that the mass movements occurred mainly on green volcanoclastic rocks and on soils derived from them, on slopes between 45 and 90 percent, at elevations between 2,300 and 2,600 feet (700-790 m), and in association with logging roads.

We have compiled data for an additional 50 events which took place in other winters since about 1950, when timber harvest and roadbuilding began in the Forest. Information was gathered from written U.S. Forest Service records made between the early 1950's and early 1960's,

conversations with R. L. Fredriksen and C. T. Dyrness (both with Pacific Northwest Forest and Range Experiment Station), sets of aerial photographs taken in 1959, 1967, and 1972, and our own field observations.

All shallow soil mass movements known to have occurred since about 1950 are shown in figure 5. Analysis of the combined data for all shallow failures reinforces the general conclusions of Dyrness (1967) based on the 1964-65 winter events alone.

Critical comparison of maps of bedrock geology and deep-seated and shallow mass movements (figs. 1, 2, and 5) reveals some additional relationships between bedrock and surficial geology. As in the case of deep-seated failures, shallow mass movements tend to occur in volcanoclastic rock terrains, especially in the contact zone where flow rocks cap clastics. Several factors contribute to the instability of this geologic setting. At elevations above the contact zone the bedrock is relatively impermeable and, in places, highly jointed; soils are shallow and stony. As a result, waters move rapidly downward into the marginally stable ground below the contact. Rapid influx of water during heavy storms produces high pore water pressures and an increased probability of mass movement.

The common occurrence of deep-seated failures in the contact zone has resulted in the accumulation of poorly consolidated, potentially unstable mass movement deposits in many areas at elevations below 3,000 feet (915 m). In several cases active deep-seated earthflows are directly responsible for the instability of areas subject to recurring shallow mass movements. For example, the active earthflows encroaching on upper Lookout Creek (location "Y" in fig. 2)

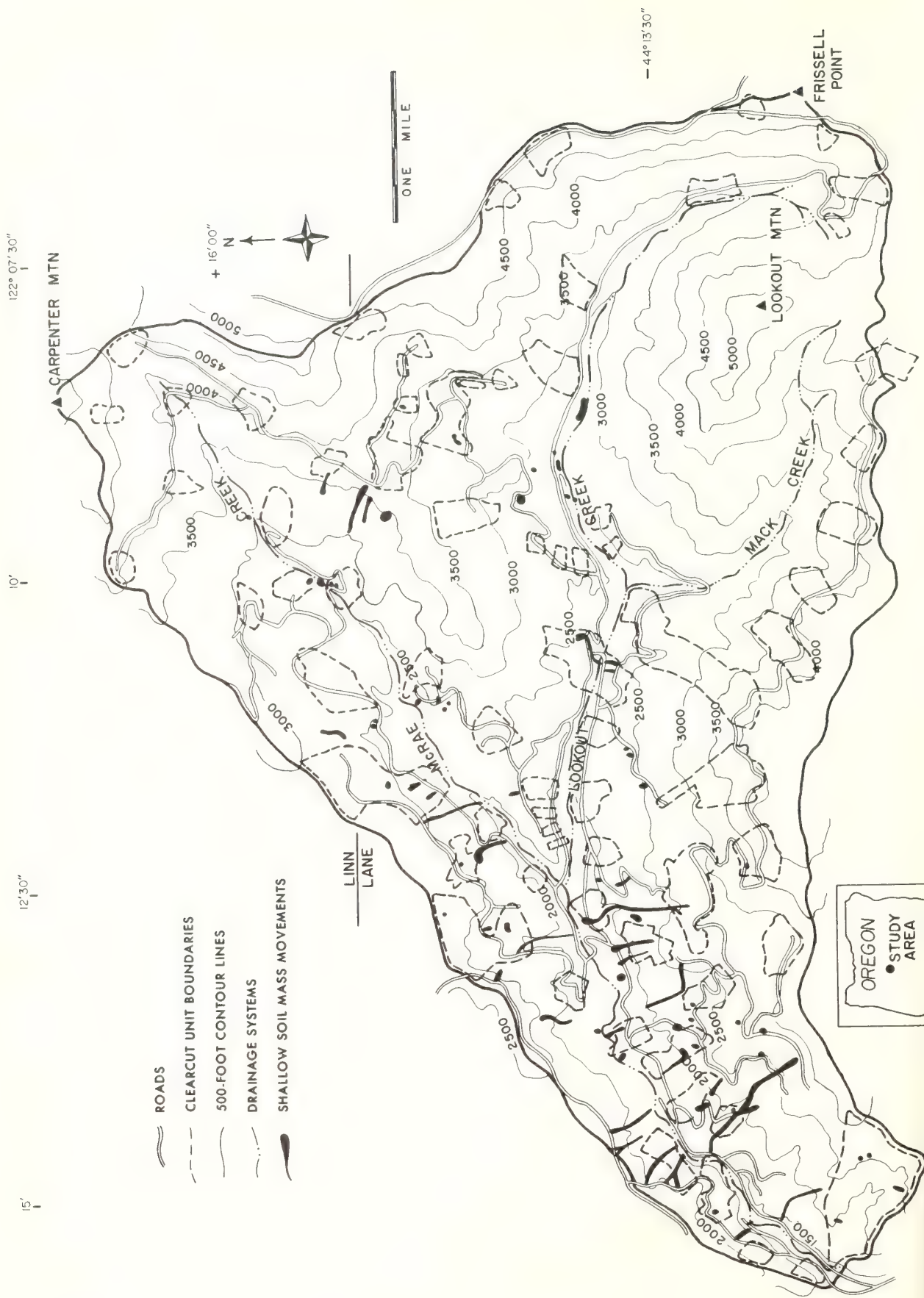
have caused numerous small streambank slumps. In another case a small, active earthflow near the headwaters of a drainage appears to have triggered repeated debris torrents down the kilometer-long channel draining the watershed.

Dyrness (1967) has shown that a major geological factor determining the occurrence of shallow mass movements is the high content of expendable clays in soils derived from volcanoclastic rocks. He noted that green colored breccias are particularly failure-prone, and Paeth (1970) found that they contain abundant zeolites which weather readily to unstable montmorillonite. Both the green coloration and the assemblage of easily weathered minerals in the breccias have been produced by several geological processes: (1) propylitic alteration involving the formation of albite, chlorite, pyrite, and other minerals by reaction with hot water circulated during the cooling of shallow intrusive bodies, (2) hydrothermal development of zeolites by circulating hot solutions or gases which may be heated either at depth or near the surface as fresh lava and ash flows cool, (3) burial metamorphism in which burial leads to increased temperature and pressure conditions and the formation of new minerals. With further study of these forms of low-grade metamorphism in the western Cascades, it will be possible to better predict the locations of unstable ground on the basis of regional geology.

## LAND MANAGEMENT IMPLICATIONS

The close relationships between geology and landscape stability established in this and earlier studies in the Forest should be considered in management planning for forest lands in the western Cascades. Potentially unstable areas may be recognized by (1) presence of altered





volcaniclastic rocks, (2) proximity to contact zones where lava flows or other relatively competent rocks overlie volcaniclastic rocks, or (3) evidence of past history of instability in the area. Areas of past and presently active instability should be identified from aerial photographs, field inspection of topography and vegetation, and even topographic maps.

Judicious use of land stability information in road placement, design, construction, and maintenance will help to minimize the types of accelerated erosion in the area documented by Dyrness (1967) and Fredriksen (1970).

## CONCLUSIONS

The geologic history of the H. J. Andrews Experimental Forest area has been one of distinct phases of volcanism interspersed with periods dominated by weathering, erosion, and the reworking of volcanic material. Paleobotanical evidence suggests that the earliest rocks, mainly mudflow and pyroclastic flow units, were erupted in late Oligocene to early Miocene time. Younger eruptive activity poured out basaltic and andesitic flows as recently as about 4 million years b.p.

Glacial, alluvial, and mass movement processes have formed the modern Lookout Creek landscape since late Pliocene time. Glaciation has formed cirques on north- and northeast-facing ridges higher than 4,500 feet (1,370 m), and glacial deposits are found along Lookout and McRae Creeks down to elevations of about 2,200 and 2,500 feet (670 and 760 m), respectively. Latest Wisconsin ice appears to have been mainly restricted to cirques and elevations above 3,800 feet (1,155 m).

Alluvial processes have constructed a modern flood plain and a terrace on which numerous small alluvial fans have

accumulated from tributary watersheds. About 3 miles (5 km) from the mouth of Lookout Creek, a massive earthflow encroached on the channel during Holocene time, resulting in the development of a very broad flood plain for about 2.8 miles (4.5 km) upstream. The section of the valley above the earthflow is also characterized by a thick wedge of sediment along the south side of the valley. This deposit accumulated before mid-Holocene time as a result of high sedimentation rates from the large glaciated and slide-prone watersheds forming the southern valley wall.

Mapping of mass movements in this study and by Dyrness (1967) has demonstrated that bedrock geology exercises significant influence on the occurrence of deep and shallow mass movements in the western Cascades. Both occur predominantly in areas underlain by volcaniclastic rocks which weather readily to deep, clay-rich soils. Landscape stability problems tend to be most severe where a contact zone of lava flow over volcaniclastic rocks occurs in the steep headwall or midbasin regions of watersheds. The capping effects of the more resistant flow rocks leads to development of critical slopes on the unstable volcaniclastic rocks. As instability is enhanced by the downcutting of streams, earthflows, slumps, and shallow soil mass movements occur. These processes are presently playing major roles in shaping those small watersheds within the Lookout Creek drainage which are in part underlain by clastic rocks.

Recognition of the various types of active or potentially active areas of the landscape is important in planning the development of any area. Landscape stability may be evaluated on the basis of several important criteria, including topography, general bedrock geology, and vegetation types and conditions. These factors can be examined by using aerial photographs, topographic maps, and field observations.

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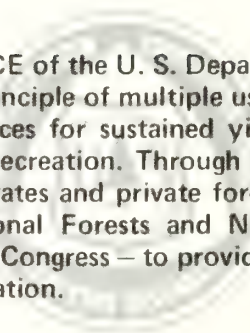
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# A Technique and Relationships for Projections of Employment in the Pacific Coast Forest Products Industries



**Brian R. Wall**  
**Daniel D. Oswald**



## Abstract

This paper presents a technique for estimating forest industry employment in the future. The authors have developed historic employment-wood consumption relationships by industry segment and geographic area. Employment trends by geographic area and industry sector are presented as essential background for projection evaluation. Seasonality information is presented to allow the interpretation of the seasonal characteristics of the employment sectors being projected.

Keywords: Forest product industries, employment (forest labor), employment (seasonal).

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## INTRODUCTION

In much of Washington, Oregon, and California, the forest industries are a major source of income and employment. Employment instability in these industries can cause severe hardships on individuals and families and economic distress in local and regional economies. In recent years there has been a realization that current high levels of timber harvest and product output on the Pacific coast, which have been sustained by harvest of diminishing reserves of old-growth timber, cannot be sustained for many more years. And more and more demands are being made for alternative uses of the region's timberlands, some of which diminish the timber output from those lands. The prospects for tightened timber supplies on the Pacific coast have implications for prices and availability of wood products in the national and international markets; but of more regional concern is the potential impact on employment and the economy.

The major purpose of this paper is to provide local and regional planners, public officials, labor representatives, and others with information and a method to help them translate future levels of timber supply and wood use by industries into future levels of direct forest industrial employment in Washington, Oregon, and California.

In the first part of the paper we describe, in general, the development of employment-raw material consumption ratios based on historical data and their use for prediction of future employment. Equations are presented for estimating future ratios for specified primary wood-using industries for half-State areas in Washington, Oregon, and California, based on the historic relationships of employment and wood consumption in those areas.

The second part of the paper presents recent trends in total employment by geographic areas and industrial sectors. Since these trends include the effect of all factors influencing employment, they provide a background against which to evaluate and adjust projections based on wood input alone. They provide the basis for extrapolating future employment, assuming continuation of trends in raw material consumption, industry mix, productivity, and utilization.

The last section deals with the seasonal variations of forest industry employment. Recognition of the seasonal patterns of the various industrial sectors is essential to interpreting projected employment's impacts on the community. Seasonality data should also be helpful to regional and community planners interested in encouraging the development of other industries whose seasonal employment patterns would offset those of the forest-related industries.

The forest industrial sectors analyzed in this study are all represented in the major categories--lumber and wood products, and paper and allied products. The lumber and wood products category includes logging activities. Employment data used in this study include all persons covered by unemployment insurance in these industries, as reported by the State employment agencies in Washington, Oregon, and California. This covered employment is subject to legal limitations of the unemployment insurance acts of the States, which have changed slightly in some forest industrial sectors since 1960. However, these changes are not significant enough to affect the findings of this study.

To make the analyses and descriptive material more useful and meaningful, each State has been divided into two units, conforming to generally recognized wood-producing regions (fig. 1). These geographic divisions have basic differences in climate, tree species, harvest techniques, and manufacturing utilization, resulting in substantially different relationships between employment and raw material consumption from one area to the next, as well as different employment trends and patterns of seasonality.

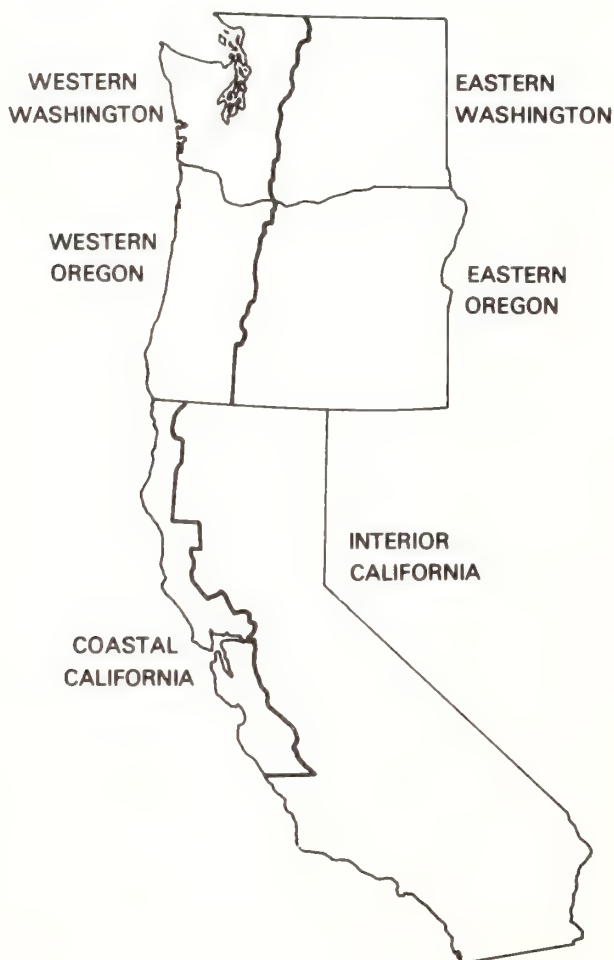


*Figure 1.--Major wood producing regions of the Pacific coast.*

## DEVELOPMENT AND USE OF EMPLOYMENT- CONSUMPTION RATIOS

Total employment levels in the forest products industries depend on many factors, including demand for the industries' products, changing product mix, increased utilization, availability of raw material, levels of capital expenditure, and skill and performance levels of labor. To predict future employment levels from these and other factors, one would have to first predict future levels for all the factors. If, on the other hand, we can define a relationship between two inputs to the manufacturing process--labor and raw material--then we can predict future levels of employment based on the predicted consumption of raw material. This approach is especially effective when dealing with the question of employment impacts of limited resource supplies in the face of increasing demand for the industries' products. This part of the paper describes the development and use of the relationship between labor and raw material inputs.

To develop ratios for use in predicting employment impacts of changing material supplies, we need a historical base of employment and raw material consumption data. Employment data are generally available from State employment security departments. Raw material consumption data are often difficult to come by. We were able to get raw material consumption data for logging and pulping. However, for lumber and plywood manufacture, we had to develop consumption estimates based on historic production levels. We used recent production-consumption ratios to develop the estimates of consumption for the historic time series. This process assumes static utilization of raw material and possibly could result in an understatement of raw material use and, consequently, an overstatement of employment requirements in the early years of the time series data. The effect of this possible bias is not known, but we feel it is nominal and does not substantially affect the relationships developed in this paper.

Since the technique of employment prediction through these ratios is generally used to determine impacts of changes in resource supply, it should be used for those industries whose operations in the area of concern will be affected by resource supply changes in that area. These include the primary resource oriented manufacturing processes: logging, lumber manufacture, plywood manufacture, and conversion of wood fiber into pulp and paper stock. The ratios should not be used for typically secondary manufacturing industries, whose location is due to market, or other nonraw material considerations.

The factors that determine the level of labor input in the production process tend to change over time in most industries and most areas; consequently, the ratio of employment to raw material consumption in the production process also tends to change over time. If a trend can be identified for such ratios--that is, if we can identify the direction and rate at which they change over time--then we can extrapolate the identified trend into the future to

predict employment required per unit of raw material consumed in the production process. This approach, of course, assumes that the aggregative effects of the changes in the underlying factors which have resulted in the historical trend in employment-consumption ratio(s) will continue into the future.

The process of extrapolation needs to be tempered by judgment based on knowledge of the industry. If the extrapolated ratios seem logical when based on the prospects that past trends will continue for the region, then the extrapolated values can be used. Employment is estimated for industry segments by applying the appropriate extrapolated ratio to the harvest or wood consumption for each point in time.

Viewed by themselves, employment-wood consumption ratios do not indicate future employment. They are only relationships by which given levels of wood inputs (raw material consumption) can be translated into employment. The future level of wood inputs to industry must be estimated and the projection period specified for the area under study. Furthermore, because employment-wood consumption ratios vary by industries, both present and future industry mix should be identified. Estimates must be made of the future quantities of wood to be consumed by sawmills, veneer and plywood plants, pulpmills, etc.; and these quantities must be consistent with the projected total wood supply.

In the next section of this paper, we have graphed the historical employment-consumption ratios for the primary manufacturing activities of the two major wood-using sectors of the Pacific coast's economy, by half-State areas. And we have fitted curve forms to these historic data, which can be extrapolated for prediction purposes. Some cautions regarding use of the curve forms are suggested.

The employment-consumption ratios used in projecting employment levels should, if possible, be developed from data for the area of concern. For instance, if projections are being made for a county, use of ratios developed for large areas, such as the half-State areas presented later in this report, could be quite inappropriate and misleading. In cases of insufficient data in a small area, ratios from a broader area can be used if it can be determined that they are similar to those for the smaller area.

Some of the curves, if extended for many years, will indicate an employment-consumption ratio approaching or reaching zero employees per unit of wood consumed. This is unrealistic. In such cases the curves should be extrapolated for only short periods into the future. When extrapolations for longer time periods are required, the user must temper the curves based on the best available evidence and expert opinion of what the employment-wood consumption relationships will be like in the future.



Finally, any one of several curve forms may adequately fit the historical trend data. The potential user is then faced with making a selection. It is often expedient to select the simplest form that adequately defines the trend. But in this as well as other aspects of selection and use of ratio trends for projection of employment in the forest products industries, considerable judgment is required of the user.

## TRENDS IN EMPLOYMENT-CONSUMPTION RATIOS IN WASHINGTON, OREGON, AND CALIFORNIA

In this section we present the historic employment-consumption ratios by half-State for logging, sawmills and planing mills, plywood and veneer plants, and pulp, paper, and board plants. Ratios for the aggregates, lumber and wood products and paper and allied products, are also presented with a discussion of the appropriateness of their use. Trends are fitted to the historic ratio data for each area-industry combination, and a determination is made of whether each ratio changes significantly with the passage of time. The ratios are expressed as man-years of employment per unit of wood raw material consumed in the manufacturing process.

### Trends in logging employment-timber harvest ratios vary by State area

Logging employment-timber harvest ratios have been calculated for western Washington, eastern Washington, western Oregon, and eastern Oregon for the 1950-70 period. Ratios were also calculated for both coastal and interior California regions for 1960-71. These ratios are expressed by average annual employment per million board feet of timber harvest (local scale). To identify trends in the ratios and provide a basis for extrapolation, we have fitted curves to the data for each region. The equation and the coefficient of determination ( $R^2$ ) for the regression are shown on the graphs.<sup>1/</sup> Figures 2 to 4 show that the curves vary by State area. Table 8 contains other regression equations for these data.

The linear form of the curves in figure 2 suggests that the combination of factors underlying the changing requirement for labor input was also changing at a constant rate in western and eastern Washington during the 1950-70 period. The downward sloping curves indicate that over the past two decades progressively fewer logging employees have been needed per million board feet of timber harvested (hereafter called unit harvest). The level of employment per unit harvest has been higher in western Washington than in eastern Washington or elsewhere on the Pacific coast.

---

<sup>1/</sup>  $R^2$  is the coefficient of determination which is a measure of how well the regression line fits the sample data.  $R^2$  is the proportion of the variation in the employment-consumption ratio which is associated with the passage of time.

One factor which could affect the employment-timber harvest ratio over time would be a possible change in average weekly hours for production workers. In theory, shorter hours could increase worker productivity. However, Bureau of Labor Statistics (1972) data indicate that the average weekly hours for production workers in logging has not changed much between 1965 and 1971 in the State of Washington. In years of peak production, the average weekly hours tend to increase. In 1971, average weekly hours worked by loggers was 36.3 hours, slightly fewer than the average for the 1965-71 period. Separate data are not available for Oregon and California, but combined sawmill and logging data for these States also suggest that average weekly hours have not changed much over the past decade. The employment-timber harvest ratios have probably not been influenced by hours worked each week.

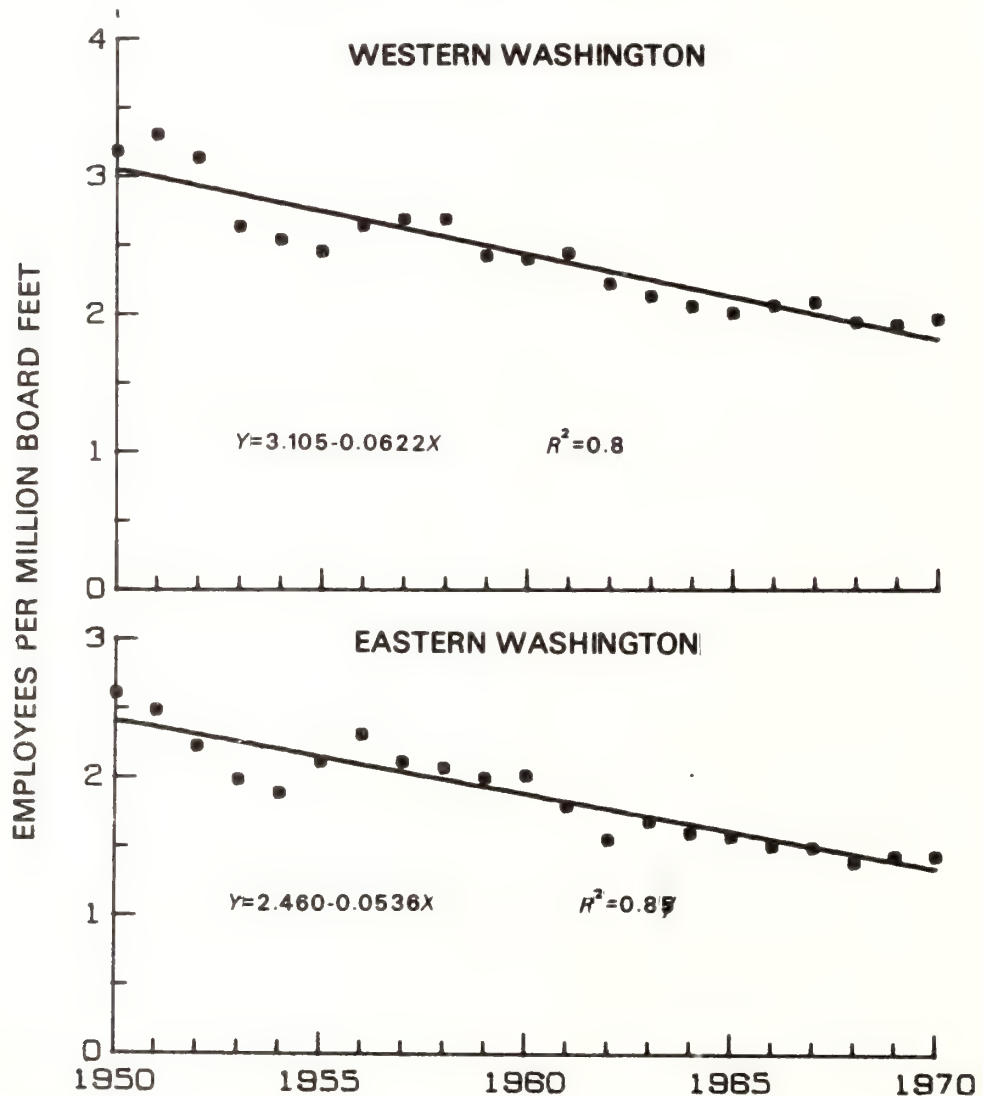


Figure 2.--Average annual employment in logging (SIC 2411) per million board feet of wood harvested in Washington by State area, 1950-70.

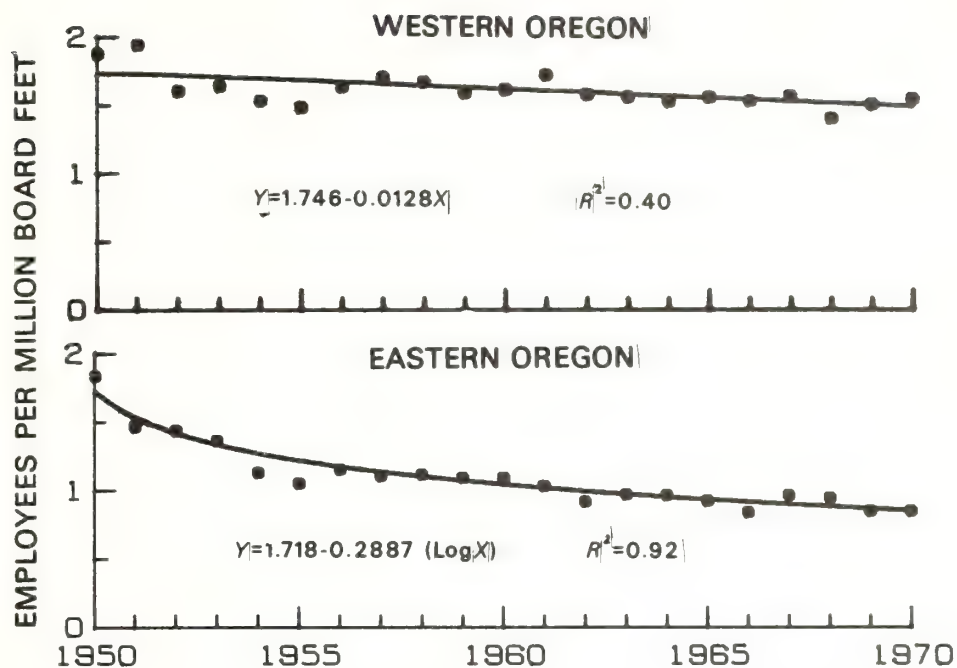


Figure 3.--Average annual employment in logging (SIC 2411) per million board feet of wood harvested in Oregon by State area, 1950-70.

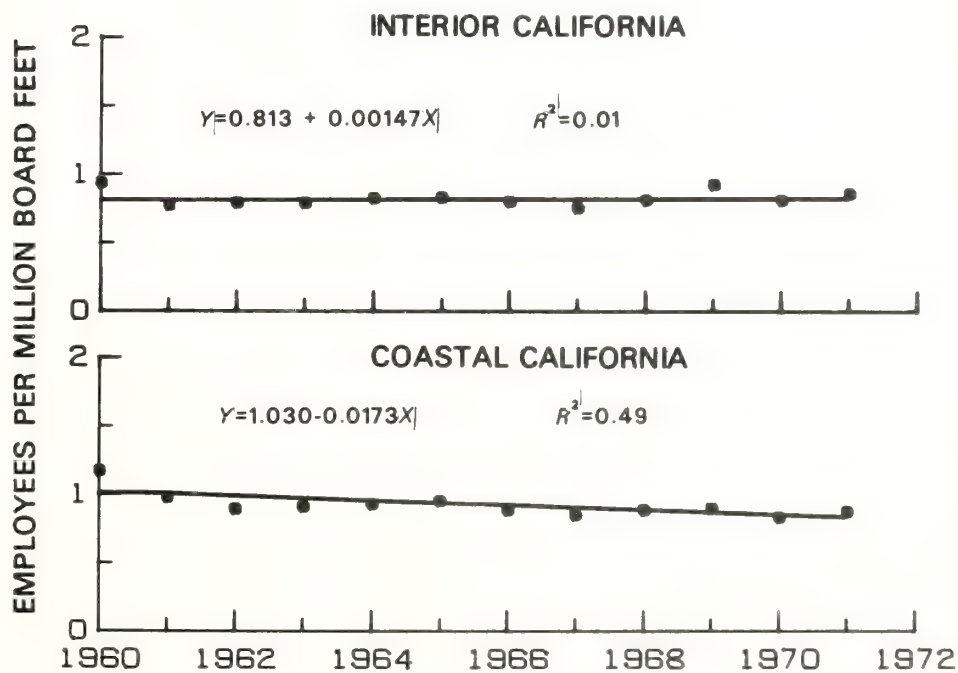


Figure 4.--Average annual employment in logging (SIC 2411) per million board feet of wood harvested in California by State area, 1960-71.

The linear relationship of declining employment per unit harvest in western Washington and eastern Washington cannot continue indefinitely. If it did, the requirement for labor to harvest timber would approach zero in both parts of the State between the years 1995 and 2000. This example points up the limitations in extrapolating the recent rates of change in these ratios indefinitely into the future. Obviously, labor will continue to be a necessary and important factor in the log production process.

Figure 3 shows the average annual employment in logging in western Oregon and eastern Oregon per unit harvest. The data for the 1950-70 period indicate slight declines in employment per unit harvest. The level of employment per unit harvest is less than in western Washington.

The data for eastern Oregon suggest the decline in logging employment per unit harvest is leveling off. Eastern Oregon logging employment ratios reached lower levels than western Oregon or Washington. Over the years, the present technology has been introduced and perhaps some temporary practical lower limit is being reached in the amount of employment required for log production.

Figure 4 shows the average annual employment per unit harvest in both interior and coastal California for 1960-71. The data show that, in both areas, logging employment per unit harvest has been lower than in Washington and Oregon.

Statistical analysis of the data for interior California reveals a very weak relationship between logging employment per unit harvest and time during the 1960-71 period. The fact that the ratios have not changed much over time is as useful as would be a changing trend in the ratio data. It indicates that the average value of  $Y$ , employees per unit harvest, is as good an estimate as exists for the period.

For coastal California, logging employment per unit harvest has declined only slightly since 1960.

### **Sawmill and planing mill manpower requirements per unit wood consumption decline**

The average annual employment in sawmills and planing mills per million board feet (log scale) of wood consumption has been declining on the Pacific coast over the past two decades. The curves of manpower requirements per unit of wood consumption vary over time by State area (figs. 5-9). The levels of labor used per unit wood input are slightly higher in western Washington sawmills than in other State areas on the Pacific coast. Table 8 shows regression equations for other curve forms fitted to the Pacific coast sawmill and planing mill data by State area.

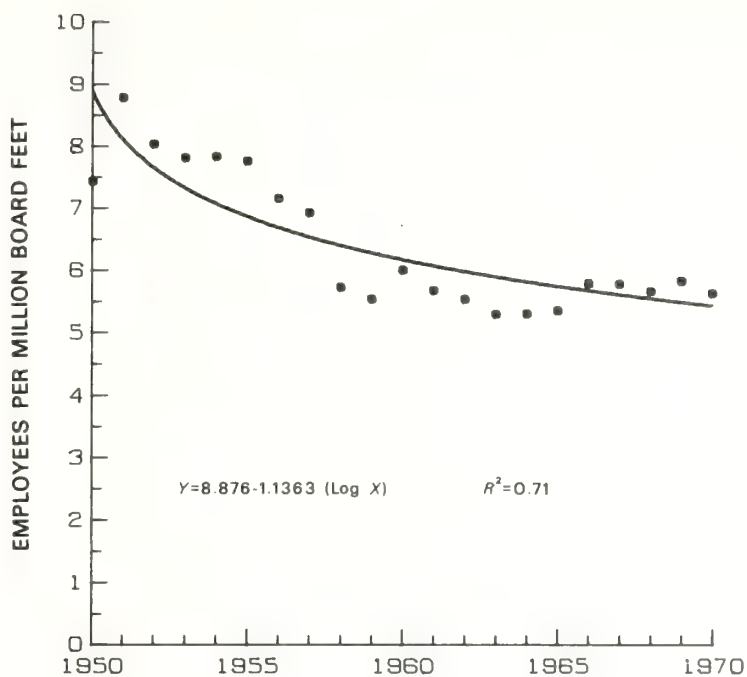


Figure 5.--Average annual employment in sawmills and planing mills (SIC 2421) per million board feet of wood consumption in western Washington, 1950-70.

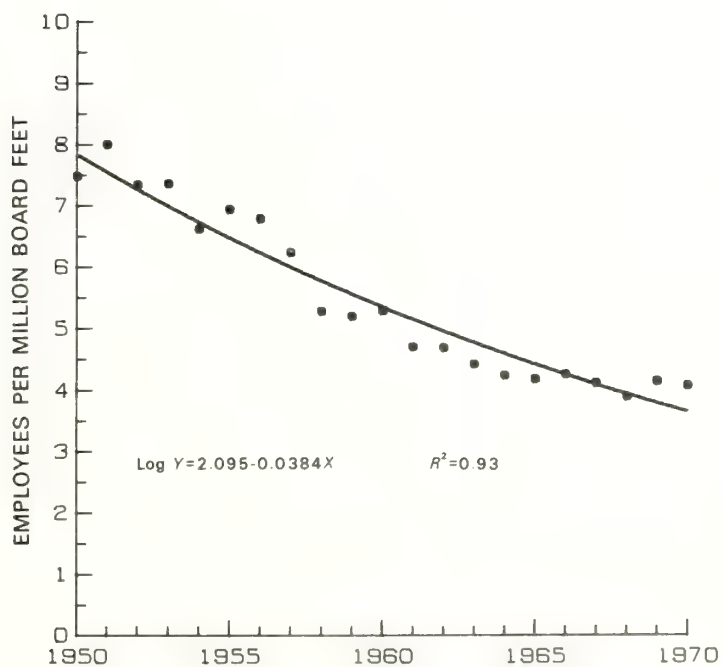


Figure 6.--Average annual employment in sawmills and planing mills (SIC 2421) per million board feet of wood consumption in western Oregon, 1950-70.



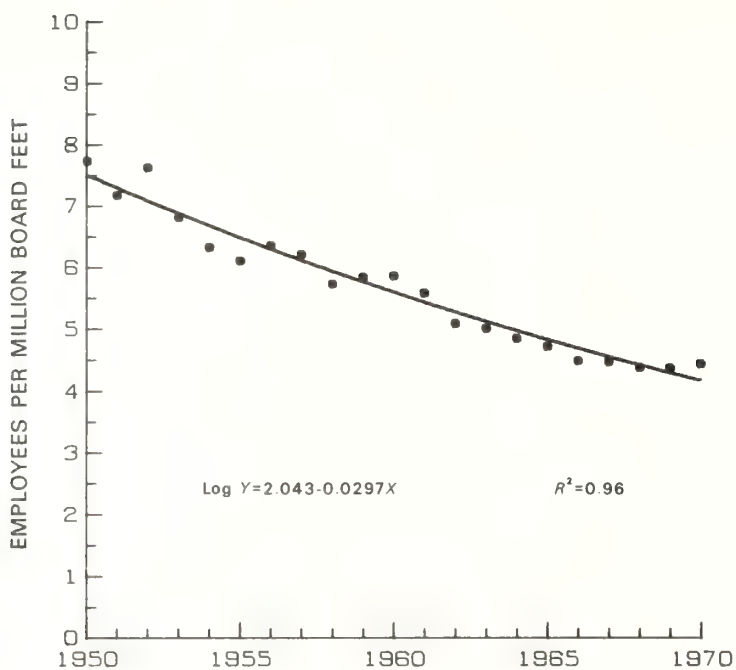


Figure 7.--Average annual employment in sawmills and planing mills (SIC 2421) per million board feet of wood consumption in eastern Washington, 1950-70.

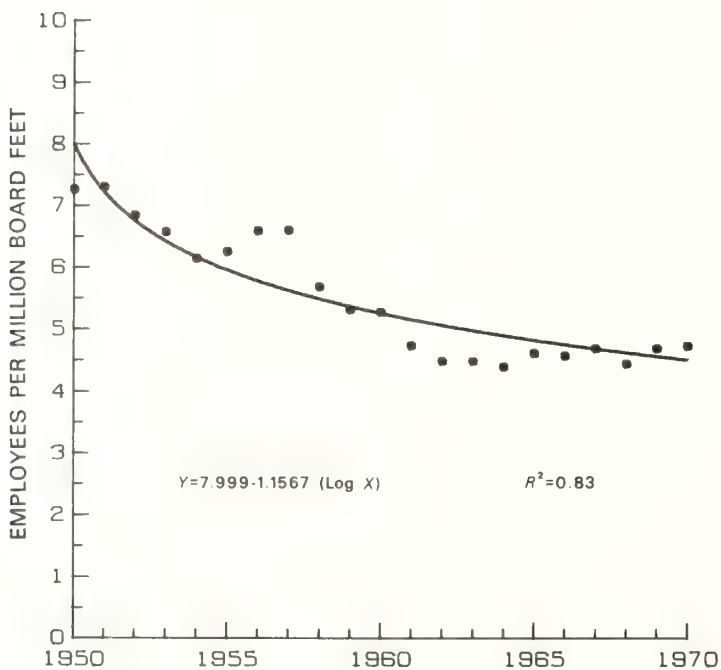


Figure 8.--Average annual employment in sawmills and planing mills (SIC 2421) per million board feet of wood consumption in eastern Oregon, 1950-70.

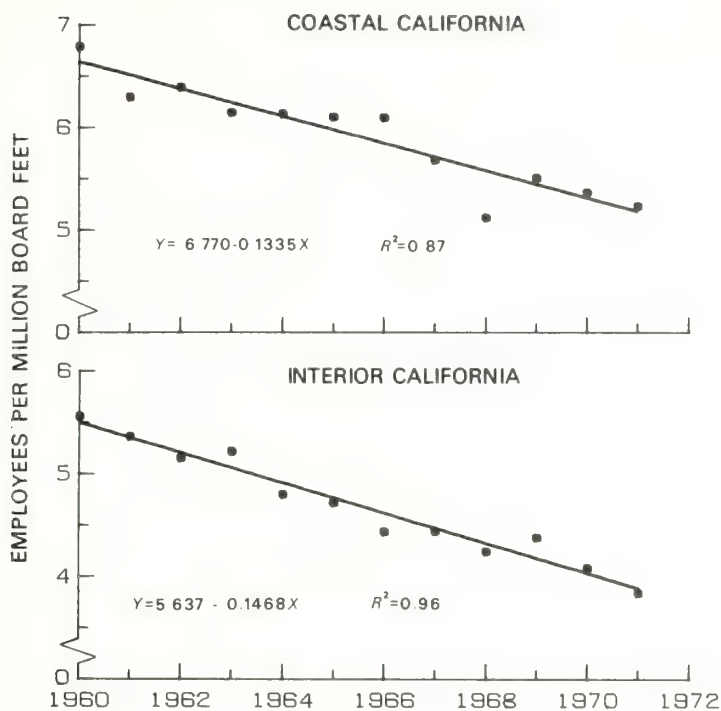


Figure 9.--Average annual employment in sawmills and planing mills (SIC 2421) per million board feet of wood consumption in California, 1960-71.

The changes in sawmill employment-wood consumption ratios cannot be attributed to changes in the duration of the workweek. Bureau of Labor Statistics data indicate that, between 1955 and 1971, average weekly hours of Washington State sawmill and planing mill production workers fluctuated with business conditions, but the trend was essentially level. In 1969, a low in average weekly hours of 37.2 was recorded; and in 1971, a peak of 39.6 hours was recorded. Data for Oregon and California are not available.

Figure 5 shows that the decline in the western Washington sawmill and planing mill employment-consumption ratios in the 1950's began to level off in the 1960's. In fact, the ratios for 1966-70 are somewhat higher on the average than for 1960-65.

Regression analysis was conducted for sawmill and planing mill employment-wood consumption ratios in western Washington for several different curve forms. The curve form (fig. 5) is certainly reasonable from an economic standpoint and, with judgment, may be used as a predictor. Other curve forms are shown in table 8.

Figure 6 shows that, unlike western Washington, the western Oregon employment-wood consumption ratios for sawmills and planing mills declined throughout most of the 1950-70 period. Whereas sawmill and planing mill

manpower requirements in western Oregon have tended to be lower than in western Washington throughout the period, the continuing decline in western Oregon has made this difference more pronounced in late 1960's. Analysis indicates a strong relationship between the variables.

Figure 7 shows that sawmill and planing mill manpower requirements per unit wood input in eastern Washington have tended continuously downward over the last two decades. By 1970, the labor requirement per million board feet of wood consumption approached 4 man-years, a level experienced only in western Oregon and in interior California. The regression in figure 7 shows a strong relationship between the ratios and time.

Figure 8 shows that employment-wood consumption ratios for the sawmills and planing mills in eastern Oregon had a declining trend during the 1950's with an upward jog in the 1955-57 period; during the 1960's, the ratios leveled out. Eastern Oregon sawmill and planing mill manpower requirements tended to be somewhat lower than those in eastern Washington during the early 1950's, but by 1970 they were slightly higher. We do not know why the manpower requirements in these two areas are taking on slightly different forms over time.

Figure 9 shows the sawmill and planing mill manpower requirements per unit wood input for California. In California, the analysis of manpower requirements is limited to the 1960-71 period because of lack of employment data for earlier years. During the past decade, the sawmill manpower requirements related to wood input have been declining. The curve forms on both figures are linear, and regression analysis indicates a strong relationship between the variables.

The drop in sawmill and planing mill manpower requirements per unit wood input shown in figures 5 through 9 indicates that major forces have been working in this industry to reduce employment. These trends in manpower requirements suggest that future sawmill employment will tend to decline even if sawmill wood consumption remains stable.

### **Veneer and plywood manpower requirements have rapidly declined**

In Washington, Oregon, and California, the employment required per million board feet of wood consumed by veneer and plywood plants has been declining sharply. Even though manpower requirements have declined in all areas, Washington veneer and plywood plants require more manpower than those in Oregon and California. Plants in Washington along Puget Sound require substantially higher than average labor inputs. This area has many specialty panel plants which produce high density overlays and hardwood panels. This requires special handling by workers and longer than average press times during the manufacturing process. These mills also produce a high proportion of sanded panels, which increase the labor requirements.

Figure 10 shows that, in Washington, average annual employment in the veneer and plywood industry per million board feet of wood consumed dropped nearly 50 percent during the 1950-70 period. In Oregon, the employment per unit wood consumption in veneer and plywood plants dropped 48 percent during the 1950-70 period (fig. 10).

The employment data used in the analysis of California requirements (fig. 11), excluded hardwood panel and prefinishing plants in Los Angeles, Orange, Riverside, San Bernardino, and Alameda Counties. Plant employment in these counties is not related to softwood consumption. During the 1960-71 period, manpower requirements related to wood consumption in softwood veneer and plywood plants dropped 28 percent.

The average weekly hours of production workers in the veneer and plywood industry in Oregon tended to be slightly higher in the mid-1960's than in the mid-1950's, according to Bureau of Labor Statistics 1972 data. In 1956, average weekly hours were 40.7. In 1968, they peaked at 43.5; and in 1971, they were 41.6. Apparently, average weekly hours fluctuate somewhat with business conditions, but the changes are not large enough to significantly affect the employment-wood consumption ratios.

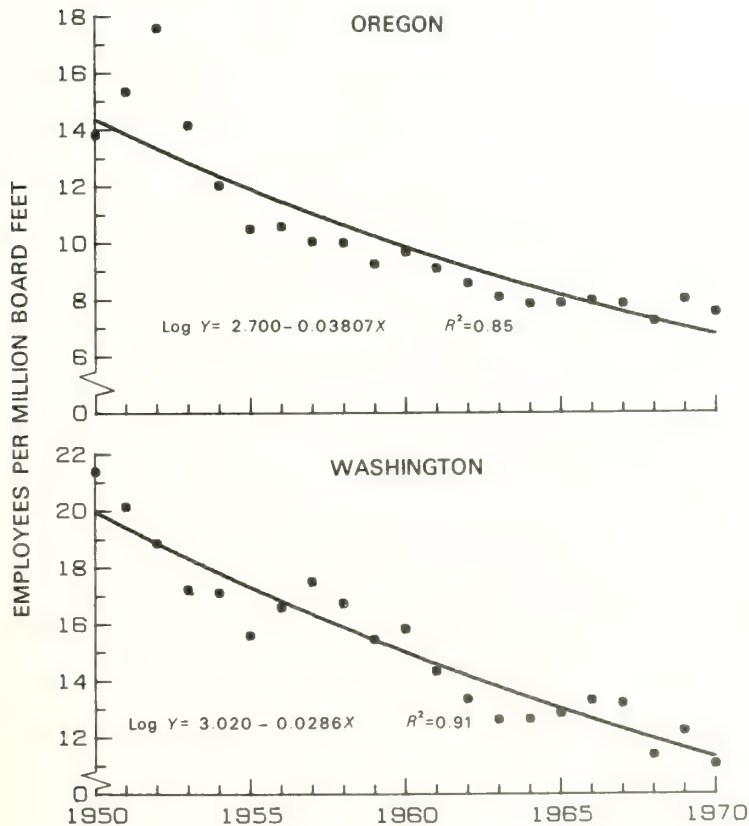


Figure 10.--Average annual employment in veneer and plywood plants (SIC 2432) per million board feet of wood consumption in Oregon and Washington, 1950-70.

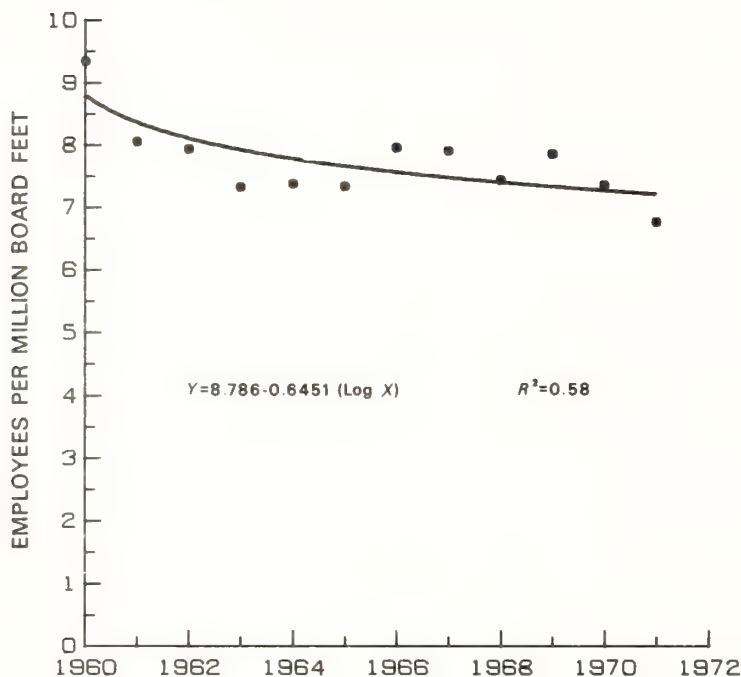


Figure 11.--Average annual employment in veneer and plywood plants (SIC 2432) per million board feet of wood consumed in California, 1960-71.

The employment-consumption ratios in the veneer and plywood industry are influenced by the change in the mix of products. There has been a shift toward production of sheathing materials rather than sanded panels. The manpower requirements are substantially less for producing sheathing, and this has tended to reduce the employment-wood consumption ratios in areas where sanded paneling production was previously high.

The closing of older, labor-intensive plants and the building of new plants which tend to produce a high proportion of sheathing have the effect of lowering the employment-wood consumption ratios over time. This has been a factor in Washington, for example. In California, the change in the number of firms operating and the number of green veneer plants relative to layup plants could influence the employment-consumption ratio.

### **Employment per unit wood consumption declines in the pulp, paper, paperboard, and building paper industries**

On the Pacific coast, the total employment per unit of wood consumption in the paper and allied products industry (SIC 26) has been declining. This relationship for the entire paper and allied products industry has commonly been used in preparing employment impacts related to timber output in resource studies for State areas. We recognize that there can be problems with this total employment method because employment in manufacture of converted paper and paperboard products and paperboard containers and boxes is not necessarily related to wood consumption in the same State area.



In California, for example, most of the total paper and allied products employment is in secondary, market-oriented activities that are little affected by wood consumption (Oswald 1970). These activities utilize purchased paper and pulp. Thus, other methods are needed to project employment for the market-oriented industry segments, especially when they are heavily concentrated in one geographic area.

In this study, we have examined not only the total employment-wood consumption relationships for the pulp, paper, and allied products industry but also the primary manufacturing-wood consumption relationships. Even this latter relationship presents problems, for it aggregates different manufacturing processes and some firms use purchased pulp instead of pulpwood as inputs. However, it does give a much firmer basis for estimated employment with respect to wood consumption than use of the entire paper and allied products sector, and it leaves the market-oriented employment to be treated in a different fashion.

Pulpwood consumption in this study includes both roundwood pulpwood and primary manufacturing residue (i.e., chips and sawdust). In California, some of the pulpwood which is consumed includes recycled waste lumber from such things as pallets, crates, etc.

Figure 12 shows two plotted sets of data and curves for the paper and allied products industry in the State of Washington. The top curve shows the

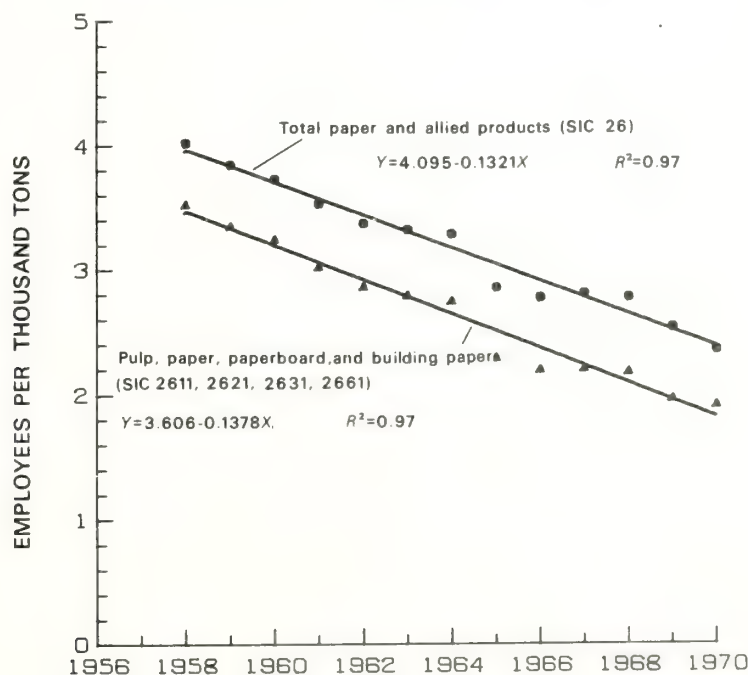


Figure 12.--Average annual employment in the total paper and allied products industry and in the pulp, paper, paperboard, and building paper industry segments per thousand tons of pulpwood consumed in Washington, 1958-70.

relationship of the total employment in the industry (SIC 26) to pulpwood consumption for the 1958-70 period. The lower curve shows the relationship for the more direct wood-consuming segments of the industry--pulp, paper, paperboard, and building paper (SIC 2611, 2621, 2631, 2661). Both curves decline sharply during the period, indicating that changes in manufacturing labor requirements have taken place. The pulp, paper, paperboard, and building paper curve is roughly parallel to the total paper and allied products curve, and analysis reveals a strong relationship between the ratios and time. The parallel nature of the two curves occurs primarily because wood-consumption-related employment accounts for most of the total paper and allied products employment. Also, secondary-manufacturing employment has tended to increase at the same time wood consumption in the primary sector has increased.

Since most of the employment in total paper and allied products in Washington is in the primary manufacturing processes, the practice of relating all employment to pulpwood consumption seems acceptable. However, we must point out that secondary manufacturing employment is not directly related to local pulpwood consumption. Use of such an extrapolated trend of ratios would not be correct if, for example, it were tied to declining or static consumption when rises in secondary employment could be anticipated.

In Washington, the employment-pulpwood consumption ratios dropped about 45 percent between 1958 and 1970 for the pulp, paper, paperboard, and building paper industry segments. A continuation of the current trend in the ratio would result in a zero labor requirement in the early 1980's. It is obvious that the recent trend will change, for even though the industry is highly mechanized, labor will continue to be needed for the manufacturing process. One clue to the level at which the employment-consumption ratios will level off may come from examining the ratios for individual new, efficient plants as an indicator of what the industry will tend to be like.

Figure 13 shows the total Oregon pulp and paper employment-wood consumption relationship for the 1958-70 period; it also shows the ratios of pulp, paper, paperboard, and building paper employment to wood consumption for the same period. For both curves, analysis indicates a strong relationship between variables. A linear curve describes the pulp, paper, paperboard, and building paper ratios over time equally well from a statistical standpoint. The employment data for both curves in figure 13 excludes the hardboard industry employment which was included in the original data reported under covered employment for the 1958-63 period.

The problem associated with using the total paper and allied products curve as a predictor is apparent for Oregon, because secondary manufacturing employment is not related directly to local pulpwood consumption. The employment in the industrial sectors, converted paper, paperboard products, paperboard containers, and boxes, has not grown relative to the increase in wood consumption in the State. In Oregon, the percentage of total employment which is secondary and market oriented is larger than in Washington.

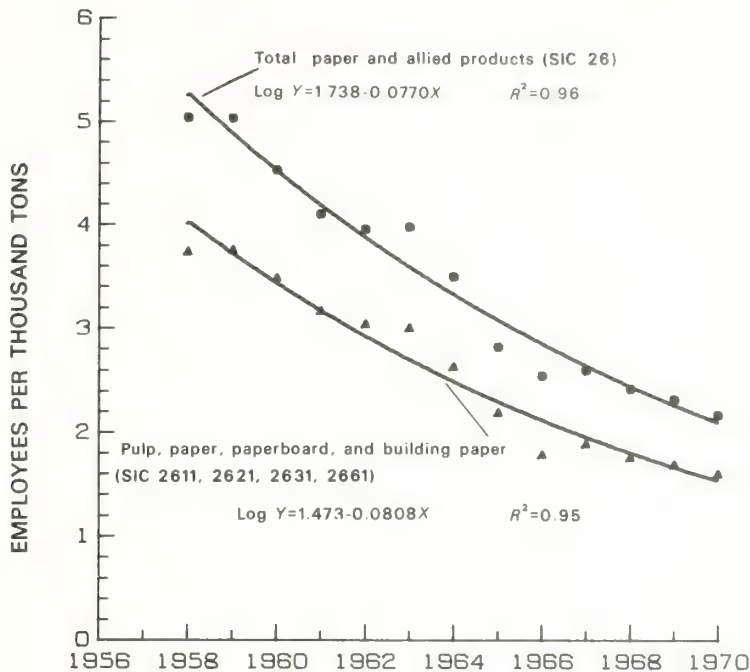


Figure 13.--Average annual employment in the total paper and allied products industry and in the pulp, paper, paperboard, and building paper segments per thousand tons of pulpwood consumed in Oregon, 1958-70. (Adjusted for hardboard reclassification.)

The larger the secondary sector relative to the primary sector when wood consumption is increasing, the more pronounced the problem of curve convergence will be. The two curves in figure 13 tend to converge. Thus, the extrapolation and use of the total paper and allied products employment-wood consumption curve would tend to underestimate total employment in future time periods. The same erroneous assumption based on the past, that paper products fabrication depends on local sources of wood, is inherent in this technique.

In California, the relationship between total paper and allied products employment and pulpwood consumption is of no practical use because most of the employment in this sector is not related to pulpwood consumption. Consequently, no curve of this relationship is shown. The top curve in figure 14 shows the average annual employment in the pulp, paperboard, and building paper industry (SIC 2611, 2621, 2631, 2661) per thousand tons of pulpwood consumed during the 1960-71 period. Analysis indicates a strong relationship between the variables. In California, a number of employees are working in mills which use purchased woodpulp from outside California and thus are not directly related to the increasing local pulpwood consumption; their inclusion affects the data and the curve. In fact, in California, only 7 of the 33 pulp, paper, paperboard, and building paper

mills in this category consumed local pulpwood. Consequently, this upper curve is unsuitable and would be misleading for projecting employment in California by employment-wood consumption ratios.

For a more realistic relationship between employment and pulpwood consumption, employment for each wood-consuming mill was identified for the 1960-71 period. The lower curve in figure 14 shows the average annual employment-consumption ratios for these selected mills. Analysis indicates a strong relationship between these ratios and time. This lower curve, based on only the mills that consumed wood, would be suitable for extrapolation of employment associated with wood consumption.

Some readers may be disappointed that we have not presented a method or equations for projection of secondary employment in the forest products industries. However, the thrust of this paper was to deal with those sectors whose employment levels are directly responsive to changes in "local" raw material supplies. There are several simple approaches for those who wish to make employment projections for the secondary forest products industries. One approach is to investigate total employment over time in any given secondary industry sector. If a definite trend can be identified, it can be extrapolated as a means of projection. This method is useful only for short periods of time since it does not use causal factors such as market growth for prediction. The trends in total employment by industry sector presented in the next section of this paper should be helpful to those interested in this type of approach.

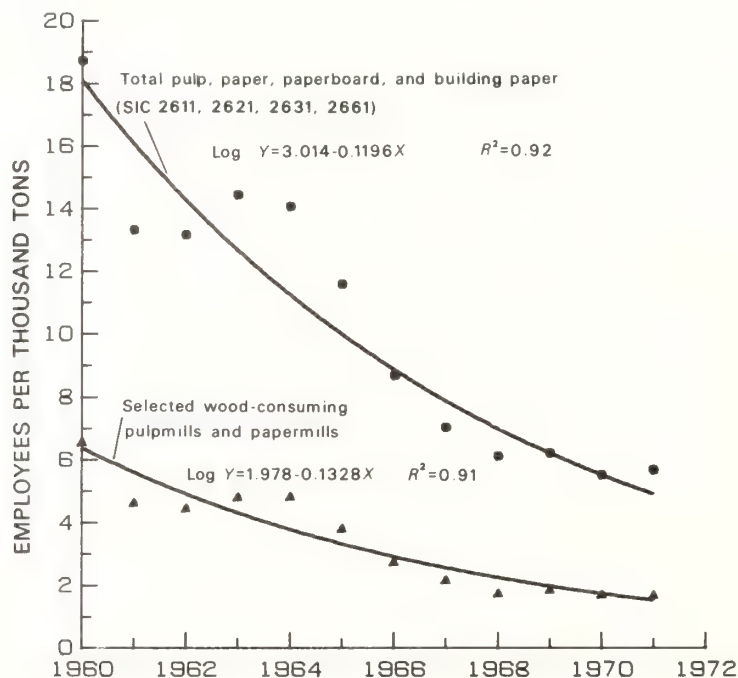


Figure 14.--Average annual employment in the pulp, paper, paperboard, and building paper industry segments of the paper and allied products industry and in selected pulpmills and papermills per thousand tons of wood consumed in California, 1960-71.



## TRENDS IN TOTAL EMPLOYMENT

This section presents the recent trends in total employment in the forest industries of the Pacific coast. For the wood-consuming industry sectors, these trends reflect both wood input-product output and labor requirements per unit of input or output. The contribution of wood consumption or production levels and labor requirements to employment trends can usually be assessed for individual industrial categories for which physical production or raw material consumption levels are identifiable. For industries where the quantity of physical outputs or material inputs is unknown, it is difficult to tell what is contributing to the trends in employment. As a generalization, however, increasing trends in employment are due to increasing production levels; decreasing trends can be due to decreasing production, decreasing labor requirements, or both.

Employment trends which are aggregates for several industrial sectors cannot be attributed directly to either labor requirement or production levels until the components of the aggregate are analyzed separately. Such aggregate trends lend themselves more readily to observation than to analysis.

### **Total forest products industries employment has been stable**

From 1950 to 1971, employment in the forest industries of the Pacific coast (Washington, Oregon, and California) has been fairly stable, varying only about 6 percent in either direction from the 228,000 average for the entire period. Employment in these industries peaked in 1951 and again in 1955 at 242,000. In 1961, a recession year for the Nation's economy, employment dipped to 213,000 (fig. 15). The fluctuations in employment are generally reflective of fluctuations in output in response to market demand and general economic conditions.

The forest industrial employment trend for California during the 1950's and 1960's was unlike the parallel Oregon and Washington trends. In California, there was a rising trend in the 1950's, and again in the 1960's following the 1960-61 recession. Employment peaked near the end of each decade. In both Oregon and Washington, employment peaked in 1951 and trended downward throughout the 1950's, becoming fairly stable during most of the 1960's.



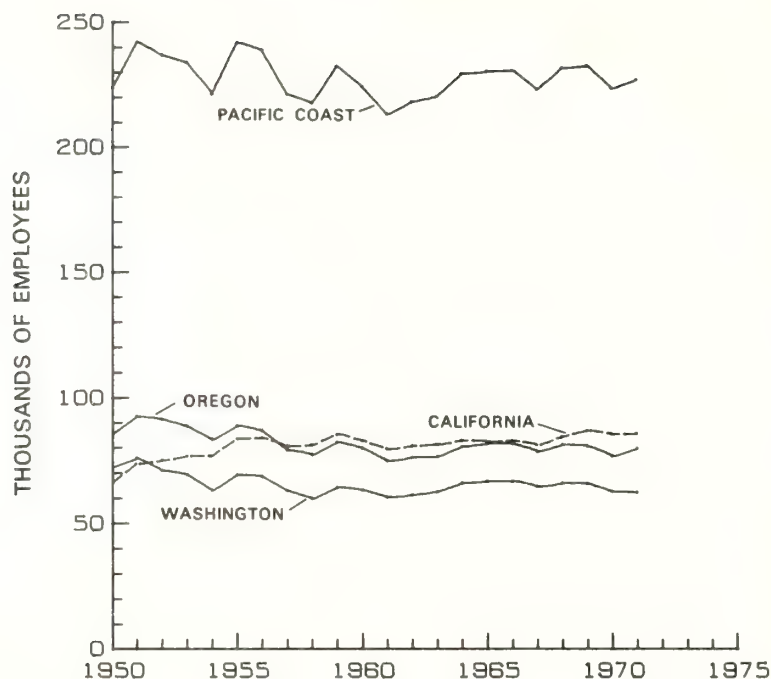


Figure 15.--Total average annual employment in the lumber and wood products and paper and allied products industries on the Pacific coast, 1950-71.

### Employment has declined in lumber and wood products manufacture

Employment in the manufacture of lumber and wood products (SIC 24) on the Pacific coast has been declining over the last two decades. From a peak of 203,000 in 1951, employment trended sharply downward during the remainder of the 1950's; employment during that period was characterized by sharp fluctuations around the trend (fig. 16). During the 1960's, the employment trend leveled considerably and the cyclical fluctuations became less pronounced. The fluctuations in employment are generally reflective of fluctuations in output in response to market demands.

The employment trends in Oregon and Washington are quite similar; in both States, employment in lumber and wood products peaked in 1951, reached a low point in 1961, and approached a stable level during the remainder of the 1960's. In California, employment peaked in 1955, but thereafter the trend paralleled those of Oregon and Washington.

Although lumber and wood products represents one major industrial sector, it is an aggregation of many distinctly different and separate manufacturing activities, including extraction of raw material (logging), manufacture of commodities (lumber and plywood), and remanufacture (millwork, prefabrication, etc.). Consequently, the trends in the overall sector represent a merging of the trends in all the individual subsectors.

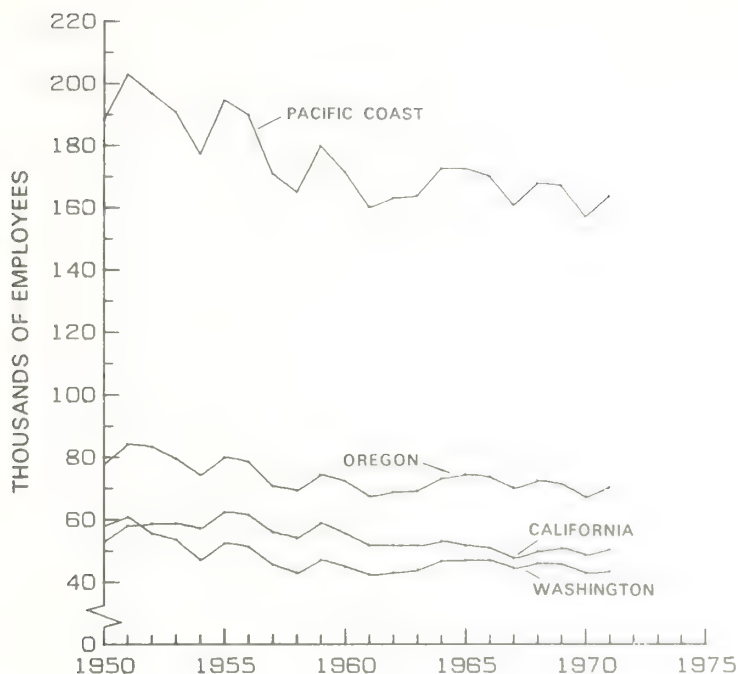


Figure 16.-- Average annual employment in the lumber and wood products industry on the Pacific coast by State, 1950-71.

### Logging employment trends vary from area to area

Distinctly different trends in logging employment are apparent between the subareas in each State. For the Pacific coast as a whole, grouping of western or coastal areas apart from eastern or interior areas does tend to combine similar producing areas which have some products and markets in common.

In western Oregon, logging employment has trended downward throughout the last two decades. By 1971, employment had declined over 30 percent from its 1951 peak. The steep downward trend in the 1950's reflects primarily the downward trend in timber harvest during that period. However, during the 1960's, the harvest fluctuated around a stable base but employment continued to decline due to the gradual downward trend in labor requirement per unit harvest (fig. 17).

In western Washington, the downward trend in logging employment of the 1950's reversed in the 1960's. During the former period, the downward trend resulted from declines in both timber harvest and labor requirements; in the 1960's, a rapidly increasing harvest trend resulted in substantial increases in logging employment, even though labor requirements in the area continued the downward trend of the 1950's.

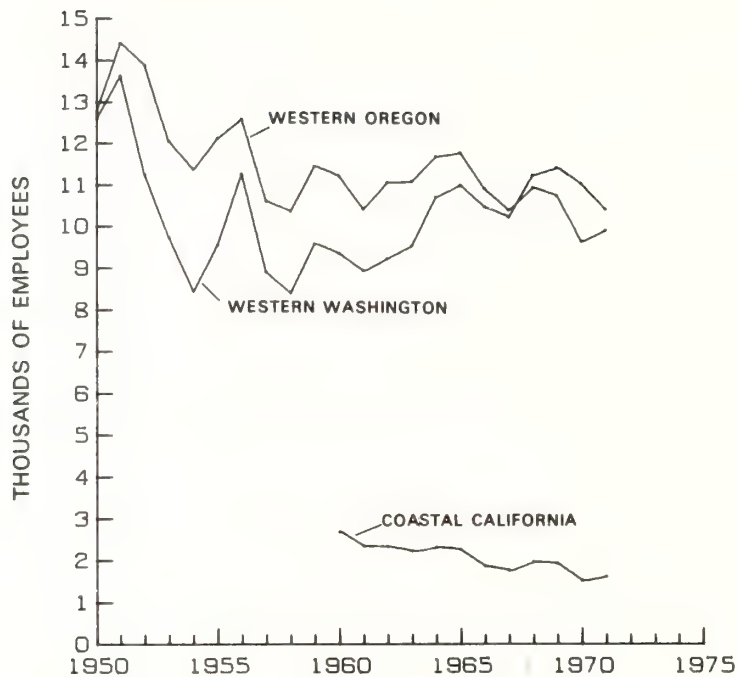


Figure 17.--Average annual employment in logging in western Washington, western Oregon, and coastal California, 1950-71.

Logging employment in coastal California declined 45 percent from 1960 to 1970. Declining harvests as well as declining labor requirements contributed to the trend.

In contrast to the complex trends and sharp fluctuations in logging employment in the western areas of the States, the eastern or interior areas have experienced relatively stable employment (fig. 18). In interior California, the harvest remained stable during the 1960's as did labor requirements, resulting in an essentially stable employment situation throughout the decade. In eastern Oregon, increasing harvests were offset by decreasing labor requirements during the 1950's, and employment was stable. The trend of increasing harvests continued in the 1960's, but labor requirements diminished at a slower rate, no longer offsetting the employment effect of increasing harvests; logging employment consequently increased throughout much of the 1960's. Logging employment in eastern Washington increased with increasing harvests in the 1950's but stabilized in the 1960's due to the offsetting trends of increasing harvests and decreasing manpower requirements.

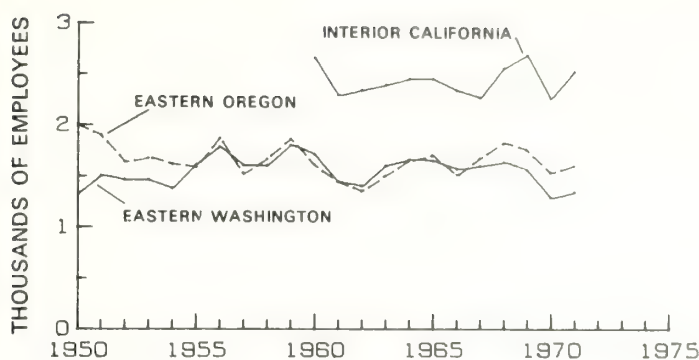


Figure 18.--Average annual employment in logging in eastern Washington, eastern Oregon, and Interior California, 1950-71.

## Employment in the manufacture of lumber has declined

Employment in sawmills and planing mills has declined substantially in Oregon, Washington, and California in the last two decades. Until recently, this manufacturing activity provided more employment than any other wood manufacturing activity in each of the three States. This is no longer true in Oregon where veneer and plywood plants are now the leading employers.

In western Oregon, employment in sawmills and planing mills trended sharply downward throughout the 1950's; during the 1960's the downward trend moderated (fig. 19). By 1970 employment in this manufacturing activity had fallen 60 percent from the 1950 level. The steep downward trend in the 1950's resulted from declining output and a 30-percent decline in labor requirements. During the 1960's, the output was fairly stable, and most of the employment decline was attributable to a moderate decline in labor requirements.

In western Washington, employment in sawmills and planing mills fell from 20,000 in 1950 to 11,400 in 1961 due to declining production and rapidly diminishing labor requirements. During the 1960's, employment stabilized as a result of stable trends in both output and labor requirements.

Coastal California employment in sawmills and planing mills declined about 25 percent during the 1960's, all of which is attributable to the diminishing requirement for labor in the lumber manufacturing process.

Except for the 1950-55 period, the employment trend in sawmills and planing mills in eastern Oregon is similar to the western Oregon pattern. The 30-percent decline in employment from 1955 to 1961 was due primarily to a 25-percent decline in labor requirements during that brief period (fig. 20). However, during the 1960's, employment declined little; during this latter period, employment requirements stabilized but production declined slightly.

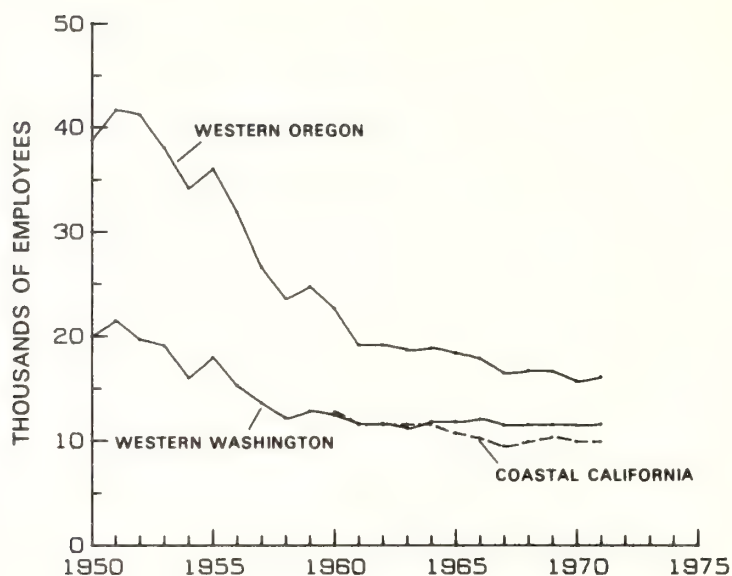


Figure 19.--Average annual employment in sawmills and planing mills in western Washington, western Oregon, and coastal California, 1950-71.

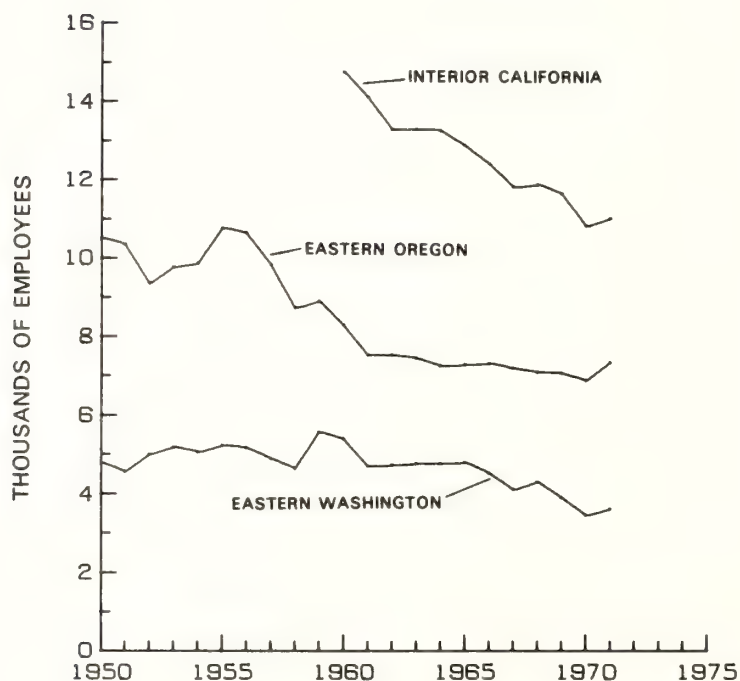


Figure 20.--Average annual employment in sawmills and planing mills in eastern Washington, eastern Oregon, and interior California, 1950-71.



In eastern Washington, there has been a rather continuous decline over the last two decades in the requirement for labor in the manufacture of lumber. Increasing production during the 1950's offset the diminishing labor requirements, and employment was fairly stable. During the early 1960's, the output continued to increase and employment remained stable, although somewhat lower than the levels of the previous decade. However, after 1965, a downward employment trend developed in response to a reversal in the trend of product output.

Interior California's employment in lumber manufacturing has trended sharply downward in the last decade, dropping 27 percent from 1960 to 1970. This area experienced the most precipitous employment decline in lumber manufacture in the 1960's of any of the half-State areas (figs. 19, 20). Production during this period has been stable; all the employment decline is attributable to decreasing manpower requirements.

### **Employment in the manufacture of veneer and plywood has decreased in recent years**

Until recent years the employment trend in Oregon's plywood industry was distinct from those of Washington and California (fig. 21). Oregon's employment more than quadrupled from 1950 to 1965 when this important industry employed 27,629 persons. During that expansion period, production increased eightfold; however, manpower requirements dropped almost 50

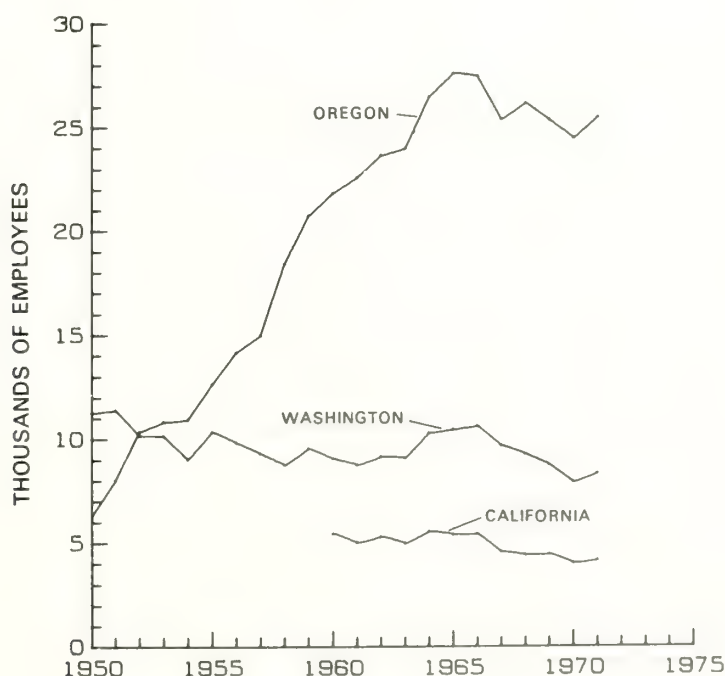


Figure 21.--Average annual employment in veneer and plywood plants in Washington, Oregon, and California, 1950-71.

percent during the same period. The decline in employment since 1965 reflects fluctuations in production and a continuation in the downward trend in labor requirements.

The softwood plywood industry pioneered in Washington. Employment in the then-mature Washington plywood industry peaked at 11,395 in 1951, then declined through the late 1950's due to decreasing labor requirements. Increasing production in the early 1960's more than offset the continuing trend of decreasing labor requirements, and employment increased to 10,612 in 1966; as production stabilized in the latter part of the 1960's, the continuing downward trend in labor requirements again was reflected in declining employment.

In California, the manpower requirements for plywood manufacture have been relatively stable throughout the 1960's. Employment in this industry was stable during the 1960-66 period but declined with lower production in the latter part of the decade.

### **Employment in other lumber and wood products industry subsectors has increased**

Employment in subsectors of the lumber and wood products industry other than logging, lumber, and veneer and plywood manufacture has generally been stable or increased during the 1960's. For these subsectors as a group, employment increased from 30,431 in 1960 to 39,315 in 1971, an increase of 29 percent. Included in this grouping of industries are manufacturers of prefabricated wooden building and structural members, wooden container manufacturers, wood preservation firms, hardwood dimension and special product sawmills, manufacturers of miscellaneous wood products including hardboard and particle board, and millwork plants. Figure 22 shows employment trends for each of these industrial subsectors.

Unlike the logging, lumber, and plywood sectors, each of which has one identifiable product, these subsectors are made up of manufacturers of many different products. Consequently, there is no common unit of raw material input or physical output within each sector, and the contributions of labor requirements and production levels to the employment trends are difficult to assess.

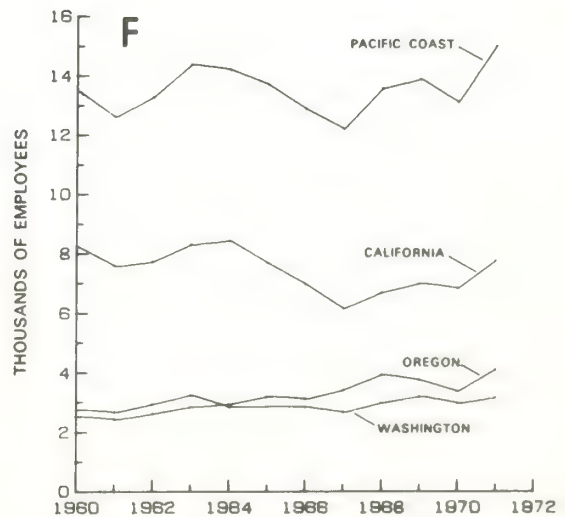
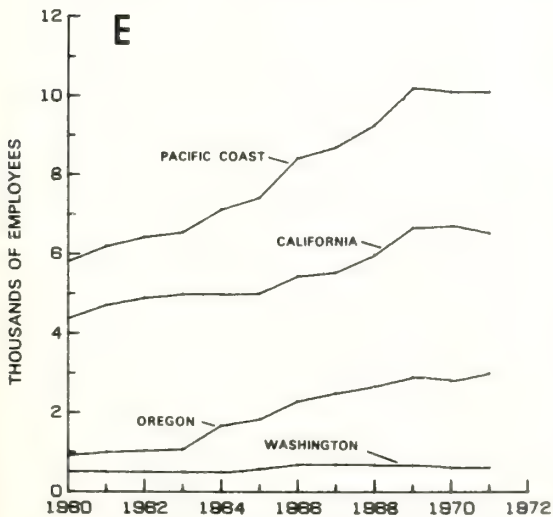
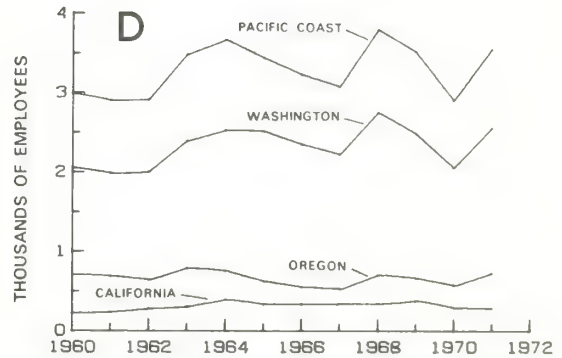
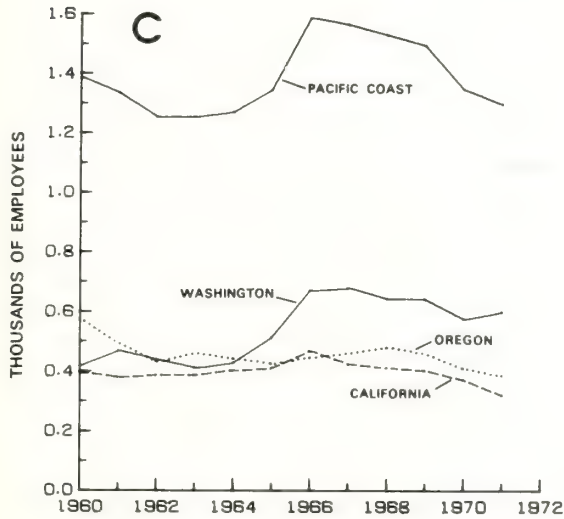
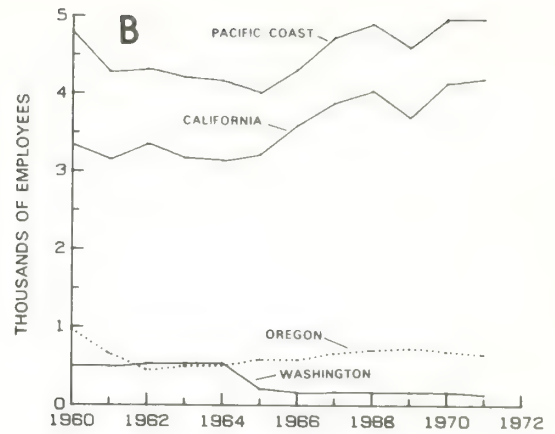
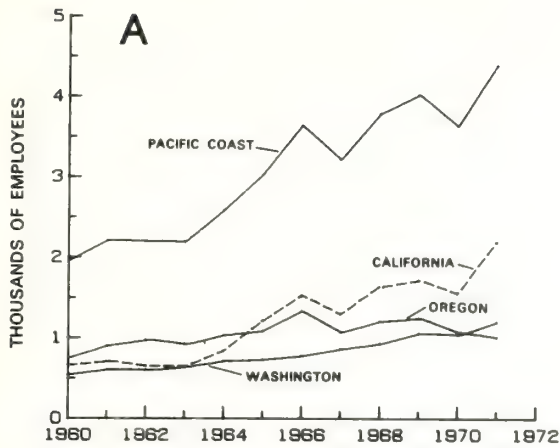


Figure 22.--Average annual employment in Washington, Oregon, and California, 1960-71, in: A, prefabricated wooden building and structural member manufacturing plants; B, wooden container manufacturing plants; C, wood preservation firms; D, hardwood dimension and flooring mills and special product sawmills; E, miscellaneous wood products manufacturing plants; and F, millwork plants.

## Employment in paper and allied products industry is on long upward trend

Between 1950 and 1971, employment in the paper and allied products industry (SIC 26) on the Pacific coast increased 90 percent. The upward trend in employment was almost continuous throughout that timespan, in each of the three States as well as for the Pacific coast (fig. 23). California, which has had the most rapid rate of growth, had 35,471 persons or 56 percent of the Pacific coast employment in this industry in 1971. Washington accounted for 29 percent (18,071 employees) of the total, and Oregon had the remaining 15 percent (9,424 employees).

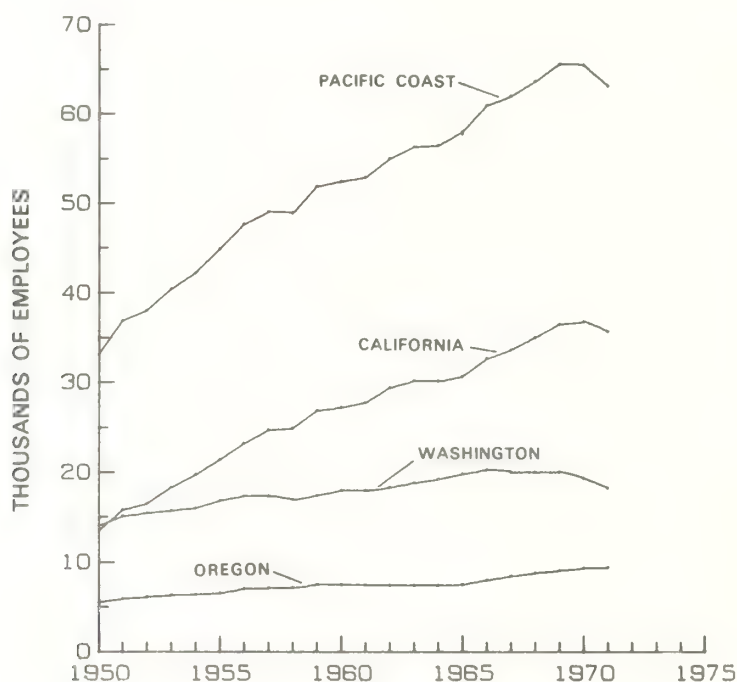


Figure 23.--Average annual employment in the paper and allied products industry in Washington, Oregon, and California, 1950-71.

## Pulp, paper, paperboard, and building paper industries employment increased during the 1960's

The pulp, paper, paperboard, and building paper sectors (SIC 2611, 2621, 2631, 2661) are the primary processing subsectors of the paper and allied products industry. Many of the manufacturing facilities have pulping equipment and thus consume pulpwood (in some form). Such firms depend

on local and regional forest resources. However, many of the manufacturing facilities included in this group (SIC 2621, 2631, and 2661) use purchased or transferred pulp instead of pulpwood. This is especially true in California where four-fifths of the establishments included do not use pulpwood.

Employment in these industries on the Pacific coast increased from 27,359 in 1960 to a peak of 31,004 in 1968; after 1968, a combination of a recessionary period and some labor disputes resulted in a downturn in employment (fig. 24). Washington experienced rather stable employment in the primary paper industries during the 1960's, a result of two offsetting trends: rising wood consumption and falling labor requirements. Oregon, like Washington, has experienced countering trends of rapidly increasing pulpwood consumption and rapidly decreasing labor requirements in primary pulp, paper, paperboard, and building paper manufacturing in the 1960's. The rate of increase of consumption, however, has exceeded the rate of decrease in labor requirements; consequently, Oregon experienced a 21-percent increase in employment in these industries from 1960 to 1970.

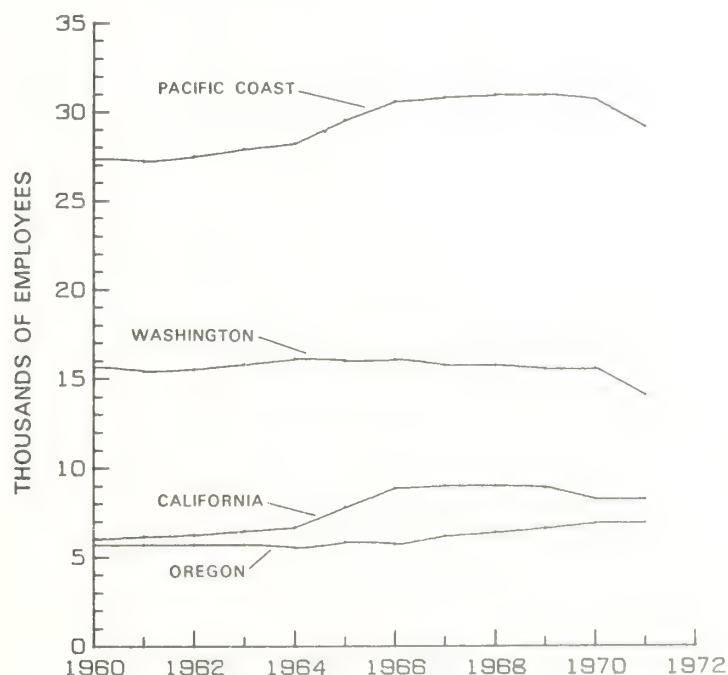


Figure 24.--Average annual employment in pulp, paper, paperboard, and building paper plants in Washington, Oregon, and California, 1960-71.

In California, employment in these primary paper industries trended upward until the late 1960's. In the pulpwood-consuming element of this industrial sector, wood consumption quadrupled during the 1960-71 period as the number of plants doubled. However, employment in these wood-using plants increased only 24 percent, because labor requirements decreased.



During this same period, employment in the nonpulpwood-consuming element of the primary paper industries experienced a more rapid growth rate--increasing 42 percent. These nonpulping paper and board mills account for 70 percent of California's primary paper manufacturing employment.

### **Employment in fabricated paper product sectors increased during the 1960's**

The two remaining major subsectors of the paper and allied products industry are remanufacturing activities concerned with the fabrication of products from paper and paperboard stock purchased or transferred from papermills or boardmills. These fabricating industries tend to be located near the markets for their product and are not dependent on a nearby supply of timber resources. Hence, the employment trends in these subsectors are related to local or regional market demand but not necessarily to local wood consumption patterns.

Employment in the manufacture of converted paper products (SIC 264) on the Pacific coast increased throughout the 1960's (fig. 25). California, which represents most of the market area for paper products on the Pacific coast, in 1971 accounted for 77 percent of the 16,360 persons employed in this sector. The growth in employment in this sector was concentrated in California and was undoubtedly related to that State's rapid population growth during the 1960's.

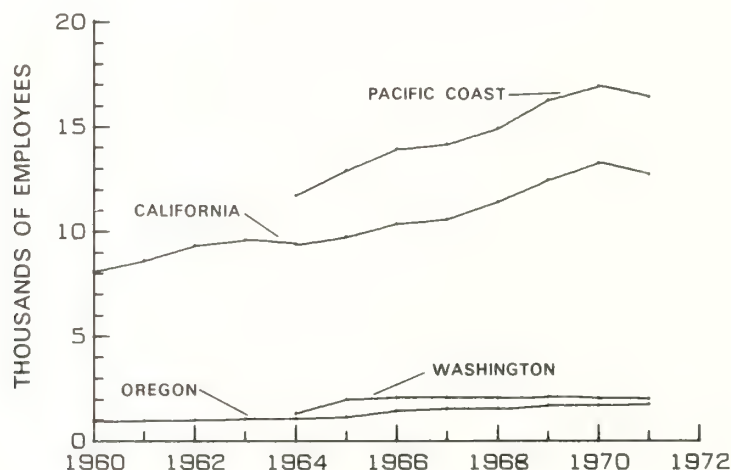


Figure 25.--Average annual employment in converted paper and paperboard products manufacturing plants in Washington, Oregon, and California, 1950-71. (Data not available for Washington before 1964.)

Trends and geographic patterns in employment in the paperboard container and box manufacturing industries (SIC 265) on the Pacific coast during the 1960's were similar to those for converted paper products (fig. 26). However, the concentration of employment in this sector in California was even greater. In 1971, 84 percent of the 17,491 persons employed in the Pacific coast paperboard container and box industries were located in California. The rate of employment growth in this sector was somewhat slower than was the rate for converted paper products.

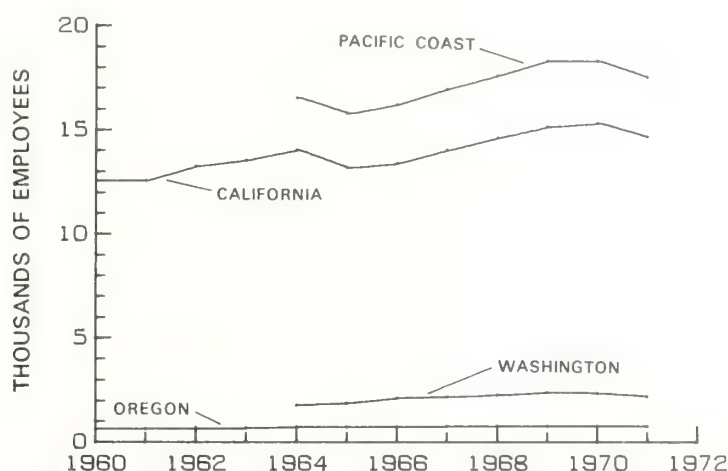


Figure 26.--Average annual employment in paperboard container and box manufacturing plants in Washington, Oregon, and California, 1960-71. (Data not available for Washington before 1964.)

## SEASONAL VARIATIONS IN EMPLOYMENT

In addition to the basic trends in employment which affect communities, the fluctuation in employment throughout the year also can have a major impact on the community's economy if it depends heavily on the fluctuating industry. Obviously, the worker employed in an industry with seasonal fluctuation directly feels the impact if he is unemployed for part of the year. The forest industries do have seasonal fluctuations, and forest-based communities have to live with this as a fact of life. Smith and Gedney (1965) documented the monthly variation in the forest products industry in Washington and Oregon for the 1957-61 period. In this section, we will discuss the seasonal fluctuation patterns for the Pacific coast for 1969-71 and compare them with those of the Smith-Gedney study. The fluctuations are presented in terms of plus or minus percentage variation from the average annual employment in an industry sector (such as logging). The percentage indicates the degree of variation, the greatest percent indicating the month of highest (+) or lowest (-) employment. The variations have not been adjusted for employment trends even though we recognize this has some influence on the results.

## Seasonal fluctuations are greatest in logging

The monthly employment in logging in Oregon, Washington, and California varied widely from winter to summer during the 1969-71 period, as would be expected for an activity dependent on good weather (fig. 27). The pattern of the variation for Washington and Oregon is very similar to that found by Smith and Gedney for the 1957-61 period. Communities which rely heavily on logging employment are faced with the effects of seasonal employment fluctuations.

During the 1969-71 period, average annual logging employment was lowest in January in western Washington (-28 percent) and in western Oregon (-20 percent). Employment rose to slightly above average in April in western Washington and in May in western Oregon and peaked in August in both areas (+11 percent in western Washington and +17 percent in western Oregon). Coastal California logging fluctuations are greater than those in western Washington and western Oregon. January and February logging employment was 47 percent below the annual average employment in coastal California; peak employment was recorded in August (+37 percent).

East of the Cascade Range and in interior California the logging employment fluctuations are more severe and the deviation pattern differs from the west side. In eastern Washington and in eastern Oregon, the monthly low employment was recorded in March (-43 percent and -50 percent, respectively). The low point in eastern Oregon was about the same as was recorded during

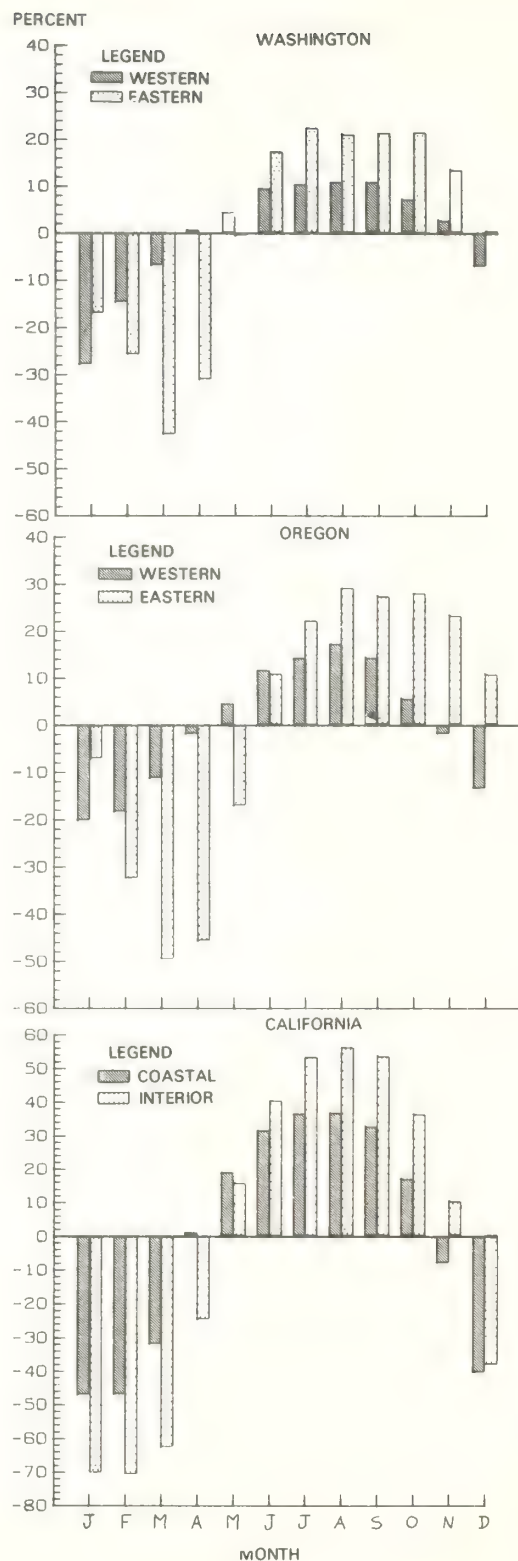


Figure 27.--Monthly deviations from average employment in the logging industry in Washington, Oregon, and California, 1969-71.

the 1957-61 period but in eastern Washington was less severe than the drop of 60 percent recorded a decade before (Smith and Gedney 1965). During the 1969-71 period, logging employment peaked in July at 22 percent above the average in eastern Washington and stayed around the 21-percent level through October. In eastern Oregon, logging employment peaked in August at 29 percent above the average and remained high in September and October. Interior California logging employment has the most severe fluctuations found in any segment of the forest products industry on the Pacific coast. January and February logging employment were below average annual employment by 70 and 71 percent, respectively. In May, interior California logging employment rose above average and peaked in August at +56 percent.

In Oregon there is evidence that the magnitude of the seasonal variation in logging (SIC 2411) steadily declined during the 1960's. This observation is based on monthly seasonal factor data supplied to us by the Oregon Employment Division of the Department of Human Resources. The data were for the whole State computed by the Seasonal Factor Method of the Bureau of Labor Statistics (BLS).

### **Seasonal employment variation in sawmills and planing mills has diminished**

Sawmills and planing mills have much less seasonal employment variation than do logging operations. For Washington and Oregon, the seasonal variation was smaller in the 1969-71 period than it was in the 1957-61 period. Smith and Gedney (1965) found that during the 1957-61 period "the range in Oregon was from 8 percent above average in August to 8 percent below in January and February. . . . In Washington these same months marked a 6 percent high and a 7 percent low in monthly employment." They also found "no differences were apparent between mills in eastern and western Oregon, but in eastern Washington the range in monthly employment was much larger from summer to winter than in western Washington."

Figure 28 shows the sawmill and planing mill seasonal fluctuations by State area for Washington, Oregon, and California for the 1969-71 period. The fluctuations in each half-State area are smaller than those found in the earlier study, and the pattern is slightly different.

In western Washington, the sawmill and planing mill employment low was in January (-3 percent below the annual average); and in western Oregon, the low was in January and February (-4 percent). The high point in western Washington was in August (+2.5 percent above average); in western Oregon it was in June (+3 percent).

East of the Cascade Range, sawmill employment fluctuated more than west of the Cascades. The eastern Washington low point in employment was in February (-6 percent), and in eastern Oregon the low point was in March



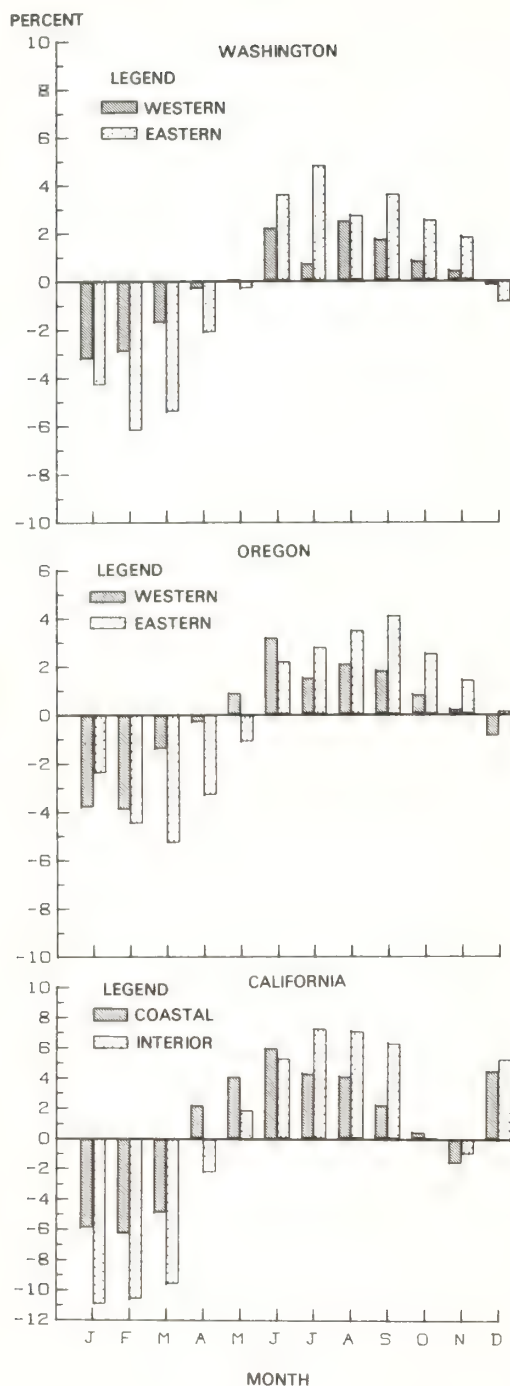


Figure 28.--Monthly deviations from average employment in sawmills and planing mills in Washington, Oregon, and California, 1969-71.

(-5 percent). The peak employment in eastern Washington was recorded in July (+5 percent); in eastern Oregon it was recorded in September (+4 percent).

California sawmills and planing mills had greater seasonal employment fluctuations in the 1969-71 period than did those in Washington and Oregon. Coastal California recorded a low in February (-6 percent) and a high in June (+6 percent). Interior California recorded a low in January (-11 percent below the annual average) and a peak in July (+7 percent).

For all of Oregon, the BLS Seasonal Factor Method data indicate that the seasonal variation for sawmills and planing mills (SIC 242) declined between 1961 and 1970. The seasonal labor force and unemployment records for Oregon seem to indicate that, even though seasonal employment and induced unemployment is declining in logging and sawmilling activities, the communities heavily dependent on them have unemployment problems which remain quite large. At present we do not know which factors account for the decline in seasonal variation, but further research in this area could lead to quicker solutions to the communities' seasonal unemployment problems.

### Fluctuations in veneer and plywood seasonal employment are small in Washington and Oregon, larger in California

During the 1969-71 period, the seasonal employment variation in Washington and Oregon veneer and plywood plants was small. Employment



in both States followed a seasonal pattern with a peak of about 2 percent above the annual average in June (fig. 29). Employment was lowest in December in Washington (-3 percent) and in February in Oregon (-2 percent). The fluctuations were slightly less than those found by Smith and Gedney for the 1957-61 period.

California veneer and plywood employment shows considerably more monthly variation than Oregon and Washington during the 1969-71 period. In January, employment was over 6 percent below the annual average. Employment peaked in April at nearly 6 percent above the annual average and remained high in May and June.

In Oregon, the amount of variation in veneer, plywood, and millwork was calculated by the BLS Seasonal Factor Method. Seasonal variation in this sector (SIC 243) has not changed to any major extent during the past decade. Because millwork was included in the factor method analysis, the results really cannot be directly compared with our measurements.

### Other segments of the lumber and wood products industry have seasonal patterns

Figure 30 shows the seasonal variation of the millwork industry for Washington, Oregon, and California during the 1969-71 period. The millwork plants in Washington State have relatively little fluctuation from month to month, whereas in Oregon and California the fluctuations are greater and the patterns differ. Both Oregon and California had low millwork employment levels in January (down over 5 percent), and both peaked in September (up over 5 percent in Oregon and 3 percent in California).

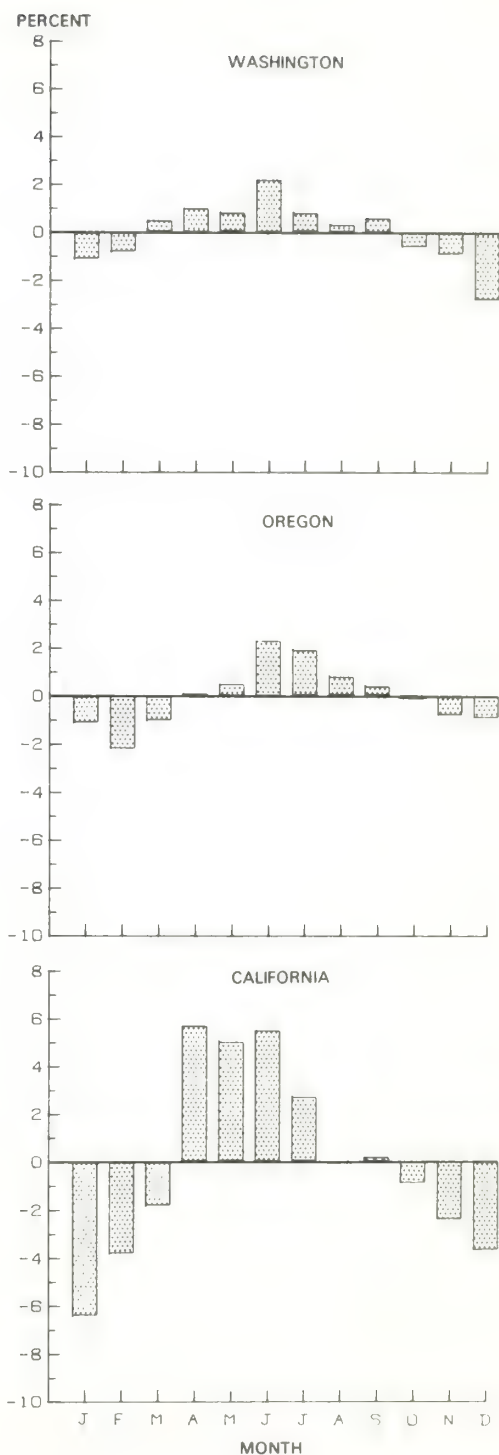


Figure 29.--Monthly deviations from average employment in the veneer and plywood plants in Washington, Oregon, and California, 1969-71.

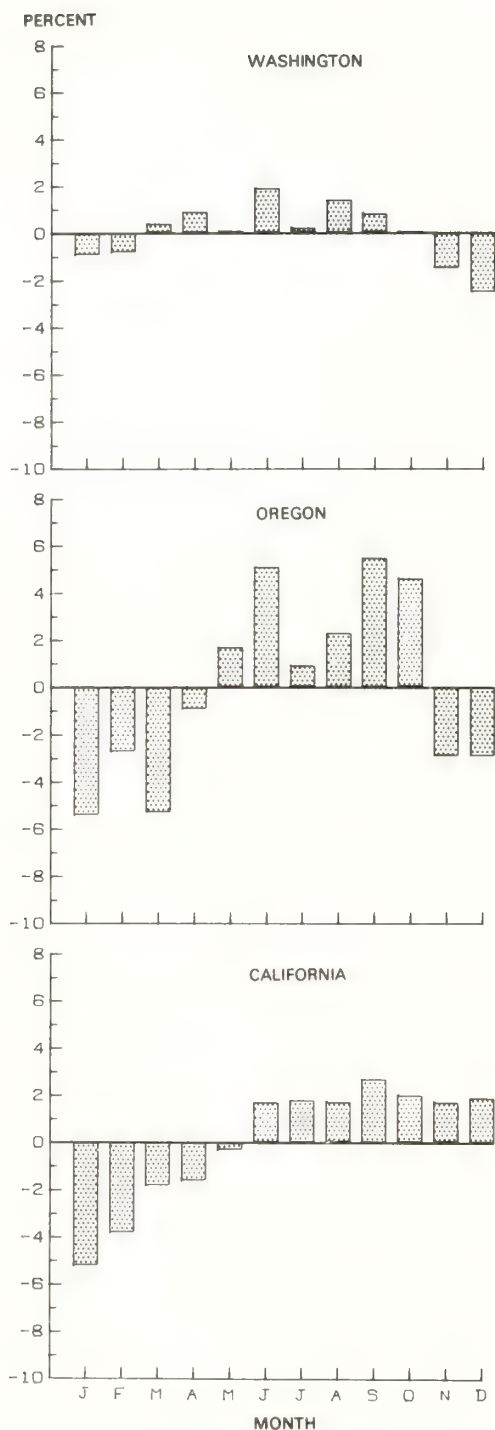


Figure 30.--Monthly deviations from average employment in mill-work plants in Washington, Oregon, and California, 1969-71.

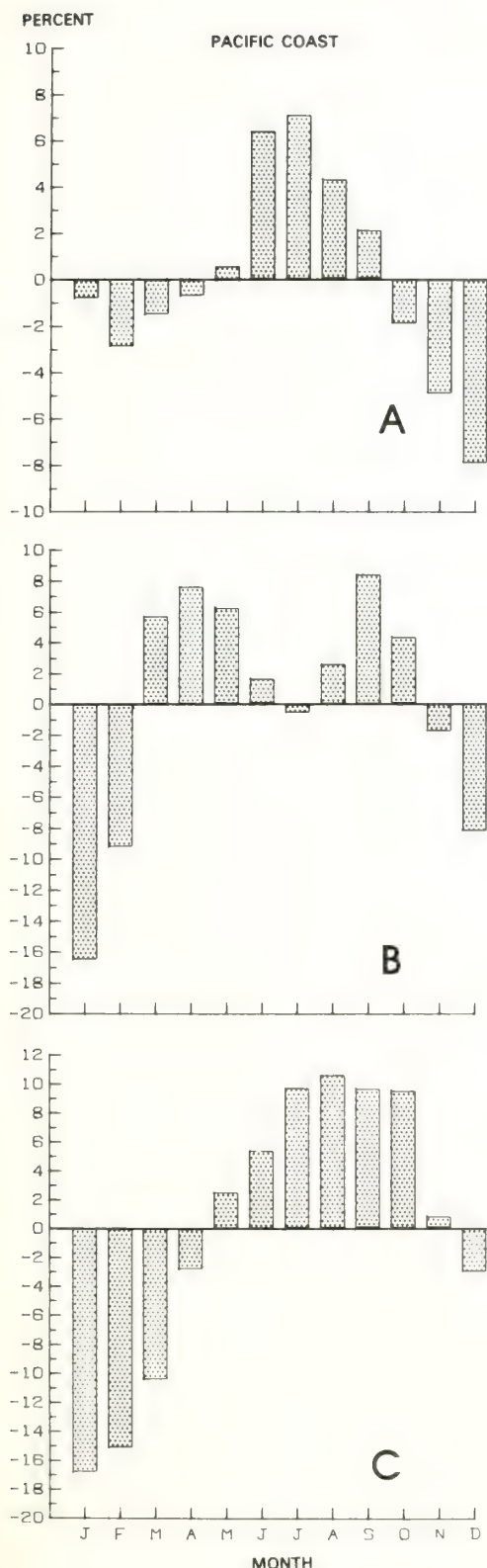
Seasonal employment fluctuations in other secondary manufacturing sectors of the lumber and wood products industry are shown in figure 31.

Special product sawmills which produce alder furniture stock and wood shingles and shakes have greater fluctuation than do the regular soft-wood lumber sawmills. On the Pacific coast, employment in this category was 16 percent below the average in January but peaked in April and in September at about 8 percent above the average.

### Labor strife distorts seasonal data for the pulp, paper, and paperboard industries

Usually the plants in the pulp, paper, and paperboard industries run at a rather steady pace throughout the year. Smith and Gedney (1965) found that during the 1957-61 period the Oregon pulp, paper, and paperboard firms experienced fairly stable employment conditions; employment varied from 4 percent above average in July to 2 or 3 percent below average from October through March. Peak summer months of employment were experienced each year.

During the 1969-71 period, California had the expected stability with employment fluctuating between plus and minus 2 percent (fig. 32). However, data for Washington and Oregon for the 1969-71 period are not typical of the usual pattern, for there were large drops in employment in April and May for the 3-year period. Closer examination of the data indicates that the April drop occurred in 1969 and the May employment drop occurred in 1971. These



unusual distortions in the monthly employment patterns are caused by labor strife at plants of several large corporations located in both Washington and Oregon. Figure 32 shows the unusual pattern for the period in Washington and Oregon as a result of these conditions.

The converted paper and paper-board products industry on the Pacific coast for the 1969-71 period shows a seasonal pattern (fig. 33). January and February are low months, somewhat less than 3 percent below the annual average employment. August and September are high months at slightly more than 2 percent above average. California, with most of the employment in this sector, had the smallest fluctuation.

The paperboard container and box industry on the Pacific coast has varying seasonal patterns by State. California has most of the employment in this sector, and its employment was more stable than either Washington's or Oregon's during the 1969-71 period, likely due to the fact that less of the total container output in California goes to the highly seasonal agricultural sector (fig. 34).

Figure 35 shows the seasonal employment variation for the building paper and building board industry on the Pacific coast. Employment in this industry is below average from October through February during the

Figure 31.--Monthly deviations from average employment on the Pacific coast, 1969-71, in the: A, wood preservation industry; B, special product sawmills industry; and C, prefabricated wooden building and structural member industry.

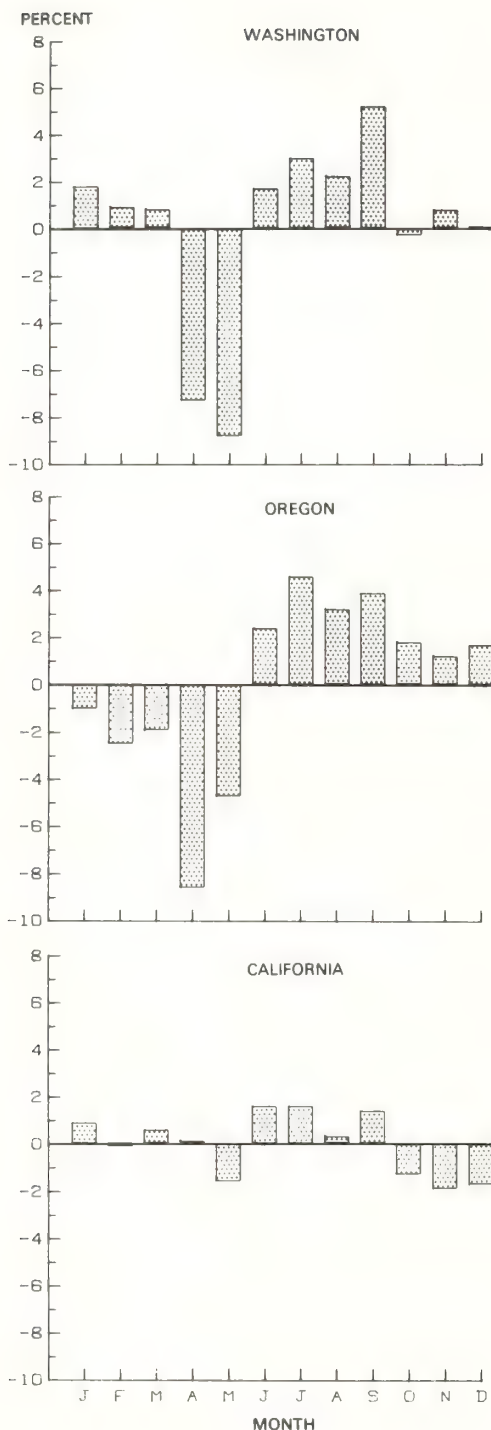


Figure 32.--Monthly deviations from average employment in the pulp, paper, and paperboard industry in Washington, Oregon, and California, 1969-71.

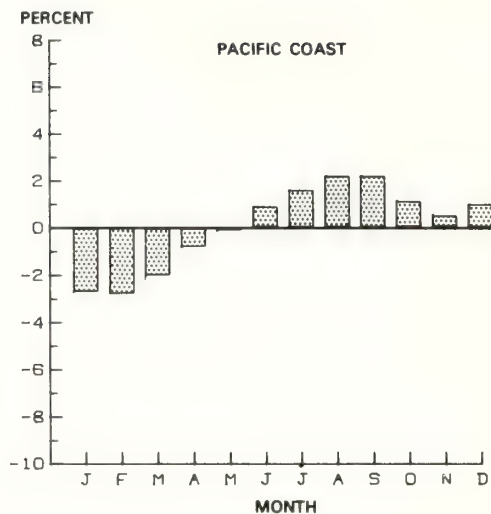


Figure 33.--Monthly deviations from average employment in the converted paper and paperboard product industry on the Pacific coast, 1969-71.

1969-71 period with a low recorded in December at over 5 percent below average. June and July were peak months at 4 percent above the annual average level of employment. The fluctuations are likely due to the seasonal pattern in construction.

Although employment in some sectors of the forest products industries displays only nominal seasonal fluctuations, it is evident that this pattern is similar for most of the sectors. The summer and early fall are periods of high production, and high employment; the early and late months of the year are characterized by lower production and employment levels. Consequently, areas with a diversity of forest products exhibit the same general seasonal employment patterns as areas with little diversity in forest products industries. The magnitude of fluctuations could of course be quite different from area to area depending on the mix of industries. There is indication that the fluctuations are lessening with the passage of time.



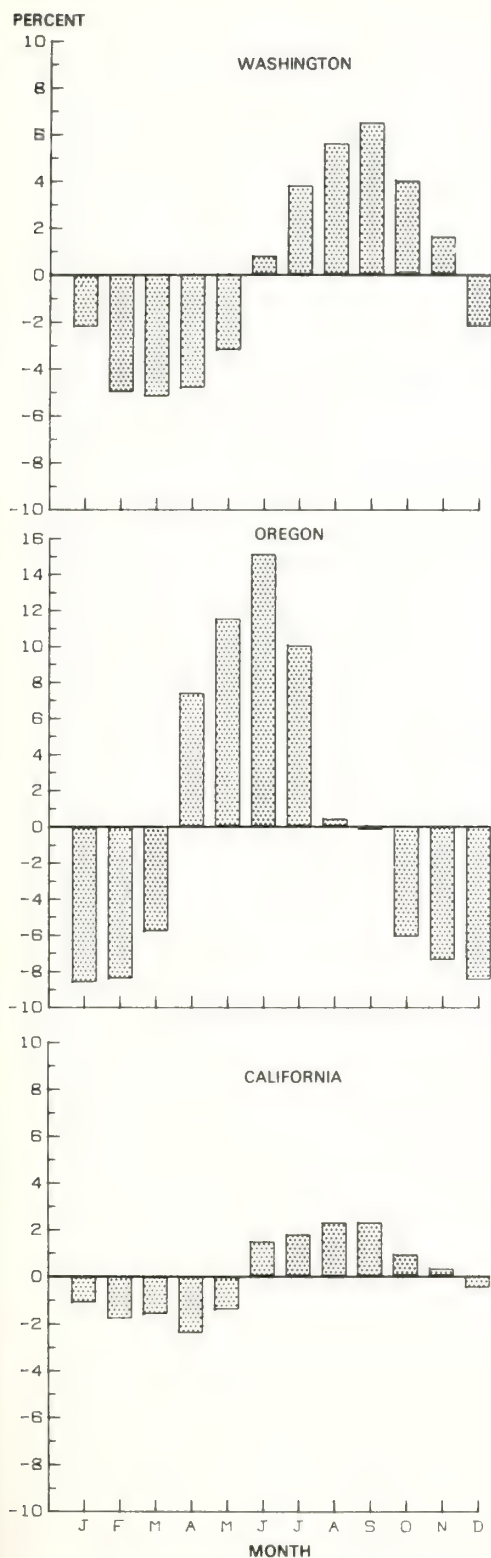


Figure 34.--Monthly deviations from average employment in the paperboard container and box industry in Washington, Oregon, and California, 1969-71.

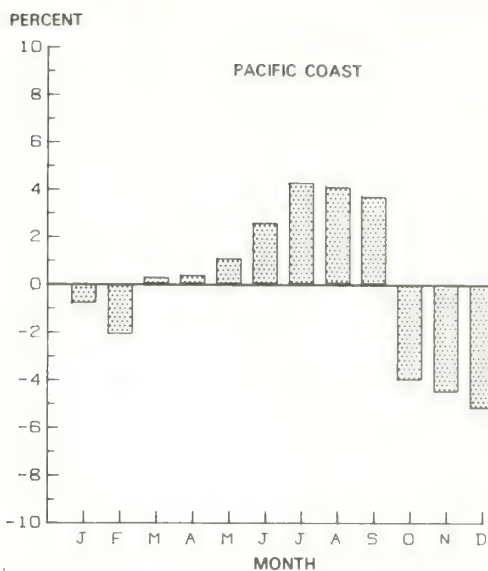


Figure 35.--Monthly deviations from average employment in the building paper and building board industry on the Pacific coast, 1969-71.

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## APPENDIX OF TABLES

*Table 1.--Average annual employment in the lumber and wood products and paper and allied products industries of Washington, Oregon, and California by State area, 1971*

| Industry                                              | Standard Industrial Classification <sup>1/</sup> | Washington          |         |        | Oregon  |         |        | California |          |        | Total Pacific coast |
|-------------------------------------------------------|--------------------------------------------------|---------------------|---------|--------|---------|---------|--------|------------|----------|--------|---------------------|
|                                                       |                                                  | Western             | Eastern | Total  | Western | Eastern | Total  | Coastal    | Interior | Total  |                     |
|                                                       |                                                  | Number of employees |         |        |         |         |        |            |          |        |                     |
| Lumber and wood products:                             |                                                  |                     |         |        |         |         |        |            |          |        |                     |
| Logging                                               | 2411                                             | 10,359              | 1,342   | 11,701 | 9,881   | 1,607   | 11,488 | 1,613      | 2,525    | 4,138  | 27,327              |
| Sawmills and planing mills                            | 2421                                             | 11,573              | 3,605   | 15,178 | 16,083  | 7,349   | 23,432 | 9,818      | 11,009   | 20,827 | 59,437              |
| Special product sawmills and hardwood mills           | 2426, 2429                                       | (2/)                | (2/)    | 2,560  | (2/)    | (2/)    | 728    | (2/)       | (2/)     | 269    | 3,557               |
| Millwork                                              | 2431                                             | 2,590               | 577     | 3,167  | 2,258   | 1,848   | 4,106  | 1,022      | 6,746    | 7,768  | 15,041              |
| Veneer and plywood                                    | 2432                                             | 7,469               | 851     | 8,320  | 24,587  | 960     | 25,547 | 2,093      | 2,073    | 4,166  | 38,033              |
| Prefabricated wooden buildings and structural members | 2433                                             | 1,006               | 190     | 1,196  | (2/)    | (2/)    | 995    | 1,068      | 1,131    | 2,199  | 4,390               |
| Wooden containers                                     | 2441, 2442, 2443, 2445                           | 95                  | 29      | 124    | 586     | 48      | 634    | 437        | 3,772    | 4,209  | 4,967               |
| Wood preserving                                       | 2491                                             | (2/)                | (2/)    | 539    | (2/)    | (2/)    | 380    | (2/)       | (2/)     | 315    | 1,234               |
| Miscellaneous wood products                           | 2499                                             | 554                 | 45      | 599    | 2,650   | 339     | 2,989  | 1,977      | 4,501    | 6,478  | 10,066              |
| Total lumber and wood products                        |                                                  | 36,658              | 6,726   | 43,384 | 58,011  | 12,288  | 70,299 | 18,119     | 32,250   | 50,369 | 164,052             |
| Paper and allied products:                            |                                                  |                     |         |        |         |         |        |            |          |        |                     |
| Pulpmills                                             | 2611                                             | 2,424               | --      | 2,424  | 301     | --      | 301    | (2/)       | (2/)     | 419    | 3,144               |
| Paper, paperboard, building paper, and building board | 2621, 2631, 2661                                 | (2/)                | (2/)    | 11,599 | (2/)    | (2/)    | 6,608  | 3,252      | 4,512    | 7,764  | 25,971              |
| Converted paper and paperboard products               | 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2649   | 1,803               | 139     | 1,942  | 1,754   | --      | 1,754  | 3,171      | 9,493    | 12,664 | 16,360              |
| Paperboard containers and boxes                       | 2651, 2652, 2653, 2654, 2655                     | 1,769               | 337     | 2,106  | 761     | --      | 761    | 4,055      | 10,569   | 14,624 | 17,491              |
| Total paper and allied products                       |                                                  | (2/)                | (2/)    | 18,071 | (2/)    | (2/)    | 9,424  | (2/)       | (2/)     | 35,471 | 62,966              |
| Total, all industries                                 |                                                  | (2/)                | (2/)    | 61,455 | (2/)    | (2/)    | 79,723 | (2/)       | (2/)     | 85,840 | 227,018             |

<sup>1/</sup> Standard Industrial Classification (SIC) for 1967.

<sup>2/</sup> State areas have been combined to avoid disclosure of individual mill statistics.



Table 3.--Average annual employment in logging (SIC 2411) in Washington  
Oregon, and California by State area, 1950-71  
(Number of employees)

| Year | Pacific<br>coast<br>total | Washington |         |         | Oregon |         |         | California |         |          |
|------|---------------------------|------------|---------|---------|--------|---------|---------|------------|---------|----------|
|      |                           | Total      | Western | Eastern | Total  | Western | Eastern | Total      | Coastal | Interior |
| 1950 | (1/)                      | 13,899     | 12,583  | 1,316   | 14,765 | 12,774  | 1,991   | (1/)       | (1/)    | (1/)     |
| 1951 | (1/)                      | 15,119     | 13,622  | 1,497   | 16,290 | 14,409  | 1,881   | (1/)       | (1/)    | (1/)     |
| 1952 | (1/)                      | 12,645     | 11,203  | 1,442   | 15,461 | 13,835  | 1,626   | (1/)       | (1/)    | (1/)     |
| 1953 | (1/)                      | 11,134     | 9,691   | 1,443   | 13,685 | 12,005  | 1,680   | (1/)       | (1/)    | (1/)     |
| 1954 | (1/)                      | 9,759      | 8,398   | 1,361   | 12,927 | 11,329  | 1,598   | (1/)       | (1/)    | (1/)     |
| 1955 | (1/)                      | 11,145     | 9,537   | 1,608   | 13,678 | 12,109  | 1,569   | (1/)       | (1/)    | (1/)     |
| 1956 | (1/)                      | 13,040     | 11,261  | 1,779   | 14,446 | 12,580  | 1,866   | (1/)       | (1/)    | (1/)     |
| 1957 | (1/)                      | 10,444     | 8,855   | 1,589   | 12,064 | 10,564  | 1,500   | (1/)       | (1/)    | (1/)     |
| 1958 | (1/)                      | 9,955      | 8,359   | 1,596   | 11,992 | 10,323  | 1,669   | (1/)       | (1/)    | (1/)     |
| 1959 | (1/)                      | 11,379     | 9,579   | 1,800   | 13,291 | 11,429  | 1,862   | (1/)       | (1/)    | (1/)     |
| 1960 | 29,080                    | 10,996     | 9,302   | 1,694   | 12,751 | 11,159  | 1,592   | 5,333      | 2,684   | 2,649    |
| 1961 | 26,676                    | 10,305     | 8,877   | 1,428   | 11,794 | 10,369  | 1,425   | 4,577      | 2,300   | 2,277    |
| 1962 | 27,605                    | 10,595     | 9,209   | 1,386   | 12,380 | 11,047  | 1,333   | 4,630      | 2,288   | 2,342    |
| 1963 | 28,253                    | 11,112     | 9,514   | 1,598   | 12,557 | 11,054  | 1,503   | 4,584      | 2,192   | 2,392    |
| 1964 | 30,428                    | 12,338     | 10,676  | 1,662   | 13,309 | 11,658  | 1,651   | 4,781      | 2,328   | 2,453    |
| 1965 | 30,719                    | 12,608     | 10,970  | 1,638   | 13,453 | 11,749  | 1,704   | 4,658      | 2,216   | 2,442    |
| 1966 | 28,479                    | 11,978     | 10,419  | 1,559   | 12,344 | 10,848  | 1,496   | 4,157      | 1,828   | 2,329    |
| 1967 | 27,761                    | 11,775     | 10,177  | 1,598   | 12,013 | 10,336  | 1,677   | 3,973      | 1,717   | 2,256    |
| 1968 | 30,089                    | 12,846     | 11,209  | 1,637   | 12,736 | 10,909  | 1,827   | 4,507      | 1,953   | 2,554    |
| 1969 | 29,941                    | 12,940     | 11,395  | 1,545   | 12,424 | 10,686  | 1,738   | 4,577      | 1,889   | 2,688    |
| 1970 | 27,081                    | 12,247     | 10,968  | 1,279   | 11,102 | 9,586   | 1,516   | 3,732      | 1,481   | 2,251    |
| 1971 | 27,327                    | 11,701     | 10,359  | 1,342   | 11,488 | 9,881   | 1,607   | 4,138      | 1,613   | 2,525    |

1/ California data for 1950-59 not available.



Table 4.--Average annual employment in sawmills and planing mills (SIC 2421) in Washington, Oregon, and California by State area, 1950-71  
(Number of employees)

| Year | Pacific coast total | Washington |         |         | Oregon |         |         | California |         |          |
|------|---------------------|------------|---------|---------|--------|---------|---------|------------|---------|----------|
|      |                     | Total      | Western | Eastern | Total  | Western | Eastern | Total      | Coastal | Interior |
| 1950 | (1/)                | 24,775     | 19,999  | 4,776   | 49,281 | 38,790  | 10,491  | (1/)       | (1/)    | (1/)     |
| 1951 | (1/)                | 26,019     | 21,491  | 4,528   | 51,933 | 41,633  | 10,300  | (1/)       | (1/)    | (1/)     |
| 1952 | (1/)                | 24,560     | 19,578  | 4,982   | 50,345 | 41,028  | 9,317   | (1/)       | (1/)    | (1/)     |
| 1953 | (1/)                | 24,117     | 18,939  | 5,178   | 47,617 | 37,850  | 9,767   | (1/)       | (1/)    | (1/)     |
| 1954 | (1/)                | 20,920     | 15,891  | 5,029   | 43,870 | 34,012  | 9,858   | (1/)       | (1/)    | (1/)     |
| 1955 | (1/)                | 23,141     | 17,911  | 5,230   | 46,754 | 36,007  | 10,747  | (1/)       | (1/)    | (1/)     |
| 1956 | (1/)                | 20,266     | 15,125  | 5,141   | 42,332 | 31,742  | 10,590  | (1/)       | (1/)    | (1/)     |
| 1957 | (1/)                | 18,302     | 13,437  | 4,865   | 36,164 | 26,375  | 9,789   | (1/)       | (1/)    | (1/)     |
| 1958 | (1/)                | 16,604     | 11,998  | 4,606   | 32,162 | 23,468  | 8,694   | (1/)       | (1/)    | (1/)     |
| 1959 | (1/)                | 18,355     | 12,790  | 5,565   | 33,620 | 24,720  | 8,900   | (1/)       | (1/)    | (1/)     |
| 1960 | 75,855              | 17,631     | 12,280  | 5,351   | 30,719 | 22,479  | 8,240   | 27,505     | 12,742  | 14,763   |
| 1961 | 68,011              | 16,078     | 11,416  | 4,662   | 26,495 | 19,006  | 7,489   | 25,438     | 11,368  | 14,070   |
| 1962 | 67,660              | 16,253     | 11,539  | 4,714   | 26,600 | 19,097  | 7,503   | 24,807     | 11,552  | 13,255   |
| 1963 | 66,376              | 15,811     | 11,048  | 4,763   | 25,961 | 18,554  | 7,407   | 24,604     | 11,332  | 13,272   |
| 1964 | 67,139              | 16,574     | 11,808  | 4,766   | 26,023 | 18,814  | 7,209   | 24,542     | 11,316  | 13,226   |
| 1965 | 65,286              | 16,471     | 11,682  | 4,789   | 25,507 | 18,230  | 7,277   | 23,308     | 10,469  | 12,839   |
| 1966 | 63,962              | 16,537     | 12,048  | 4,489   | 25,022 | 17,705  | 7,317   | 22,403     | 10,031  | 12,372   |
| 1967 | 59,867              | 15,394     | 11,314  | 4,080   | 23,465 | 16,320  | 7,145   | 21,008     | 9,233   | 11,775   |
| 1968 | 61,309              | 15,799     | 11,506  | 4,293   | 23,715 | 16,667  | 7,048   | 21,795     | 9,916   | 11,879   |
| 1969 | 60,794              | 15,363     | 11,503  | 3,860   | 23,492 | 16,474  | 7,018   | 21,939     | 10,334  | 11,605   |
| 1970 | 57,676              | 14,760     | 11,342  | 3,418   | 22,372 | 15,532  | 6,840   | 20,544     | 9,751   | 10,793   |
| 1971 | 59,437              | 15,178     | 11,573  | 3,605   | 23,432 | 16,083  | 7,349   | 20,827     | 9,818   | 11,009   |

1/ California data for 1950-59 not available.

Table 5.--Average annual employment in veneer and plywood plants (SIC 2432), Washington, Oregon, and California, 1950-71

(Number of employees)

| Year | Pacific coast total | Washington | Oregon | California |
|------|---------------------|------------|--------|------------|
| 1950 | (1/)                | 11,280     | 6,290  | (1/)       |
| 1951 | (1/)                | 11,395     | 7,989  | (1/)       |
| 1952 | (1/)                | 10,100     | 10,369 | (1/)       |
| 1953 | (1/)                | 10,086     | 10,837 | (1/)       |
| 1954 | (1/)                | 8,977      | 10,956 | (1/)       |
| 1955 | (1/)                | 10,344     | 12,625 | (1/)       |
| 1956 | (1/)                | 9,789      | 14,149 | (1/)       |
| 1957 | (1/)                | 9,243      | 14,968 | (1/)       |
| 1958 | (1/)                | 8,701      | 18,428 | (1/)       |
| 1959 | (1/)                | 9,548      | 20,729 | (1/)       |
| 1960 | 36,292              | 9,005      | 21,849 | 5,438      |
| 1961 | 36,238              | 8,696      | 22,600 | 4,942      |
| 1962 | 38,136              | 9,146      | 23,693 | 5,297      |
| 1963 | 37,958              | 9,033      | 24,007 | 4,918      |
| 1964 | 42,312              | 10,271     | 26,504 | 5,537      |
| 1965 | 43,439              | 10,480     | 27,629 | 5,330      |
| 1966 | 43,463              | 10,612     | 27,435 | 5,416      |
| 1967 | 39,462              | 9,623      | 25,363 | 4,476      |
| 1968 | 39,754              | 9,216      | 26,196 | 4,342      |
| 1969 | 38,470              | 8,703      | 25,342 | 4,425      |
| 1970 | 36,277              | 7,856      | 24,470 | 3,951      |
| 1971 | 38,033              | 8,320      | 25,547 | 4,166      |

<sup>1/</sup> California data for 1950-59 not available.

Table 6.--Average annual employment in the paper and allied products industry (SIC 26) in Washington, Oregon, and California, 1950-71<sup>1/</sup>  
(Number of employees)

| Year | Pacific coast total <sup>2/</sup> | Washington | Oregon | California <sup>2/</sup> |
|------|-----------------------------------|------------|--------|--------------------------|
| 1950 | 33,100                            | 14,067     | 5,538  | 13,500                   |
| 1951 | 36,900                            | 15,100     | 5,917  | 15,800                   |
| 1952 | 38,000                            | 15,440     | 6,129  | 16,500                   |
| 1953 | 40,400                            | 15,703     | 6,363  | 18,300                   |
| 1954 | 42,200                            | 16,039     | 6,412  | 19,700                   |
| 1955 | 44,900                            | 16,881     | 6,584  | 21,400                   |
| 1956 | 47,600                            | 17,311     | 7,059  | 23,200                   |
| 1957 | 49,000                            | 17,202     | 7,091  | 24,700                   |
| 1958 | 48,700                            | 16,803     | 7,072  | 24,900                   |
| 1959 | 51,900                            | 17,387     | 7,558  | 26,900                   |
| 1960 | 52,471                            | 17,967     | 7,310  | 27,194                   |
| 1961 | 52,902                            | 17,844     | 7,261  | 27,797                   |
| 1962 | 54,948                            | 18,302     | 7,278  | 29,368                   |
| 1963 | 56,318                            | 18,804     | 7,366  | 30,148                   |
| 1964 | 56,476                            | 19,249     | 7,229  | 29,998                   |
| 1965 | 57,961                            | 19,776     | 7,520  | 30,665                   |
| 1966 | 60,952                            | 20,266     | 8,046  | 32,640                   |
| 1967 | 61,956                            | 19,879     | 8,464  | 33,613                   |
| 1968 | 63,687                            | 19,940     | 8,774  | 34,973                   |
| 1969 | 65,533                            | 19,979     | 9,103  | 36,451                   |
| 1970 | 65,274                            | 19,146     | 9,361  | 36,767                   |
| 1971 | 62,966                            | 18,071     | 9,424  | 35,471                   |

<sup>1/</sup> Includes hardboard manufacturing employment through 1963.

<sup>2/</sup> Source of California data for 1950-59: Bureau of Labor Statistics, U.S. Department of Labor.

Table 7.--Average annual employment in pulp, paper, paperboard, and building paper establishments<sup>1/</sup> in Washington, Oregon, and California, 1960-71

| Year | Pacific coast total | Washington | Oregon | California <sup>2/</sup> |
|------|---------------------|------------|--------|--------------------------|
| 1960 | 27,359              | 15,638     | 5,705  | 6,016                    |
| 1961 | 27,124              | 15,313     | 5,679  | 6,132                    |
| 1962 | 27,480              | 15,553     | 5,674  | 6,253                    |
| 1963 | 27,912              | 15,823     | 5,641  | 6,448                    |
| 1964 | 28,216              | 16,103     | 5,440  | 6,673                    |
| 1965 | 29,564              | 15,914     | 5,849  | 7,801                    |
| 1966 | 30,608              | 16,063     | 5,659  | 8,886                    |
| 1967 | 30,862              | 15,661     | 6,176  | 9,025                    |
| 1968 | 31,004              | 15,668     | 6,384  | 8,952                    |
| 1969 | 30,944              | 15,468     | 6,635  | 8,841                    |
| 1970 | 30,665              | 15,576     | 6,908  | 8,181                    |
| 1971 | 29,115              | 14,023     | 6,909  | 8,183                    |

<sup>1/</sup> SIC codes 2611, 2621, 2631, 2661.

<sup>2/</sup> Excludes hardboard manufacturing employment.

*Table 8.--Equations showing the relationship of employment per unit of wood consumption with respect to time  
by industry category and State area*

| State area<br>and<br>industry                                              | SIC code                     | Equation                         | F value | Period  | R <sup>2</sup> | Degrees<br>of<br>freedom |
|----------------------------------------------------------------------------|------------------------------|----------------------------------|---------|---------|----------------|--------------------------|
| Western Washington<br>logging <sup>1/</sup>                                | 2411                         | $Y = 3.105 - 0.0622X$            | 114.1   | 1950-70 | 0.86           | 19                       |
| Eastern Washington<br>logging <sup>1/</sup>                                | 2411                         | $Y = 2.460 - 0.0536X$            | 107.3   | 1950-70 | .85            | 19                       |
| Washington veneer<br>and plywood <sup>1/</sup>                             | 2432                         | $Y = 20.019 - 0.4376X$           | 160.9   | 1950-70 | .89            | 19                       |
|                                                                            |                              | $Y = 22.380 - 3.3201 \log X$     | 159.8   | 1950-70 | .89            | 19                       |
|                                                                            |                              | $\log Y = 3.159 - 0.2101 \log X$ | 108.1   | 1950-70 | .85            | 19                       |
|                                                                            |                              | $\log Y = 3.020 - 0.0286X$       | 193.6   | 1950-70 | .91            | 19                       |
| Western Washington<br>sawmills and<br>planing mills <sup>1/</sup>          | 2421                         | $Y = 8.051 - 0.1482X$            | 43.0    | 1950-70 | .69            | 19                       |
|                                                                            |                              | $Y = 8.876 - 1.1363 \log X$      | 46.1    | 1950-70 | .71            | 19                       |
|                                                                            |                              | $\log Y = 2.211 - 0.1689 \log X$ | 44.9    | 1950-70 | .70            | 19                       |
|                                                                            |                              | $\log Y = 2.089 - 0.0220X$       | 42.9    | 1950-70 | .69            | 19                       |
| Eastern Washington<br>sawmills and<br>planing mills <sup>1/</sup>          | 2421                         | $Y = 7.519 - 0.1689X$            | 306.8   | 1950-70 | .94            | 19                       |
|                                                                            |                              | $Y = 8.375 - 1.2562 \log X$      | 179.3   | 1950-70 | .90            | 19                       |
|                                                                            |                              | $\log Y = 2.180 - 0.2146 \log X$ | 126.8   | 1950-70 | .87            | 19                       |
|                                                                            |                              | $\log Y = 2.043 - 0.0297X$       | 458.7   | 1950-70 | .96            | 19                       |
| Washington paper<br>and allied<br>products <sup>2/</sup>                   | 26                           | $Y = 4.095 - 0.1321X$            | 361.1   | 1958-70 | .97            | 11                       |
|                                                                            |                              | $Y = 4.291 - 0.6459 \log X$      | 95.5    | 1958-70 | .90            | 11                       |
|                                                                            |                              | $\log Y = 1.490 - 0.2009 \log X$ | 65.2    | 1958-70 | .86            | 11                       |
|                                                                            |                              | $\log Y = 1.435 - 0.0420X$       | 338.6   | 1958-70 | .97            | 11                       |
| Washington pulp, paper,<br>paperboard, and<br>building paper <sup>2/</sup> | 2611<br>2621<br>2631<br>2661 | $Y = 3.606 - 0.1378X$            | 336.4   | 1958-70 | .97            | 11                       |
|                                                                            |                              | $Y = 3.819 - 0.6783 \log X$      | 106.8   | 1958-70 | .91            | 11                       |
|                                                                            |                              | $\log Y = 1.389 - 0.2521 \log X$ | 70.9    | 1958-70 | .87            | 11                       |
|                                                                            |                              | $\log Y = 1.3193 - 0.05251X$     | 386.7   | 1958-70 | .97            | 11                       |
| Western Oregon<br>logging <sup>1/</sup>                                    | 2411                         | $Y = 1.746 - 0.0128X$            | 12.5    | 1950-70 | .40            | 19                       |
| Eastern Oregon<br>logging <sup>1/</sup>                                    | 2411                         | $Y = 1.466 - 0.0338X$            | 51.1    | 1950-70 | .73            | 19                       |
|                                                                            |                              | $Y = 1.718 - 0.2887 \log X$      | 232.3   | 1950-70 | .92            | 19                       |
|                                                                            |                              | $\log Y = 0.581 - 0.2370 \log X$ | 230.2   | 1950-70 | .92            | 19                       |
|                                                                            |                              | $\log Y = 0.388 - 0.0290X$       | 75.4    | 1950-70 | .80            | 19                       |
| Oregon veneer<br>and plywood <sup>1/</sup>                                 | 2432                         | $Y = 14.6011 - 0.4969X$          | 64.3    | 1950-70 | .77            | 19                       |
|                                                                            |                              | $Y = 16.9486 - 3.1578 \log X$    | 79.5    | 1950-70 | .81            | 19                       |
|                                                                            |                              | $\log Y = 2.904 - 0.2879 \log X$ | 103.3   | 1950-70 | .85            | 19                       |
|                                                                            |                              | $\log Y = 2.700 - 0.03807X$      | 108.2   | 1950-70 | .85            | 19                       |
| Western Oregon<br>sawmills and<br>planing mills <sup>1/</sup>              | 2421                         | $Y = 7.832 - 0.2135X$            | 194.2   | 1950-70 | .91            | 19                       |
|                                                                            |                              | $Y = 8.886 - 1.5746 \log X$      | 117.0   | 1950-70 | .86            | 19                       |
|                                                                            |                              | $\log Y = 2.270 - 0.2768 \log X$ | 99.0    | 1950-70 | .84            | 19                       |
|                                                                            |                              | $\log Y = 2.095 - 0.0384X$       | 258.0   | 1950-70 | .93            | 19                       |

Table 8.--Equations showing the relationship of employment per unit of wood consumption with respect to time by industry category and State area--Continued

| State area and industry                                                              | SIC code                     | Equation                         | r value | Period  | r    | Degrees of freedom |
|--------------------------------------------------------------------------------------|------------------------------|----------------------------------|---------|---------|------|--------------------|
| Eastern Oregon sawmills and planing mills <sup>1/</sup>                              | 2421                         | $Y = 7.172 - 0.1521X$            | 91.9    | 1950-70 | 0.83 | 19                 |
|                                                                                      |                              | $Y = 7.999 - 1.1567 \log X$      | 94.4    | 1950-70 | .83  | 19                 |
|                                                                                      |                              | $\log Y = 2.125 - 0.2023 \log X$ | 79.4    | 1950-70 | .81  | 19                 |
|                                                                                      |                              | $\log Y = 1.985 - 0.0270X$       | 92.1    | 1950-70 | .83  | 19                 |
| Oregon paper and allied products <sup>2/</sup>                                       | 26                           | $Y = 5.297 - 0.2619X$            | 237.5   | 1958-70 | .96  | 11                 |
|                                                                                      |                              | $Y = 5.697 - 1.2876 \log X$      | 91.0    | 1958-70 | .89  | 11                 |
|                                                                                      |                              | $\log Y = 1.835 - 0.3665 \log X$ | 59.5    | 1958-70 | .84  | 11                 |
|                                                                                      |                              | $\log Y = 1.738 - 0.07699X$      | 293.5   | 1958-70 | .96  | 11                 |
| Oregon pulp, paper, paperboard, and building paper <sup>2/</sup>                     | 2611<br>2621<br>2631<br>2661 | $Y = 4.0275 - 0.2042X$           | 236.2   | 1958-70 | .96  | 11                 |
|                                                                                      |                              | $Y = 4.313 - 0.9887 \log X$      | 70.5    | 1958-70 | .87  | 11                 |
|                                                                                      |                              | $\log Y = 1.566 - 0.3798 \log X$ | 48.2    | 1958-70 | .81  | 11                 |
|                                                                                      |                              | $\log Y = 1.473 - 0.0808X$       | 230.4   | 1958-70 | .95  | 11                 |
| Interior California logging <sup>1/</sup>                                            | 2411                         | $Y = 0.813 + 0.00147X$           | .085    | 1960-71 | .01  | 10                 |
| Coastal California logging <sup>1/</sup>                                             | 2411                         | $Y = 1.030 - 0.0173X$            | 9.5     | 1960-71 | .49  | 10                 |
| California veneer and plywood <sup>1/</sup>                                          | 2432                         | $Y = 8.451 - 0.1138X$            | 7.0     | 1960-71 | .41  | 10                 |
|                                                                                      |                              | $Y = 8.786 - 0.6451 \log X$      | 13.9    | 1960-71 | .58  | 10                 |
|                                                                                      |                              | $\log Y = 2.172 - 0.0796 \log X$ | 13.1    | 1960-71 | .57  | 10                 |
|                                                                                      |                              | $\log Y = 2.133 - 0.0143X$       | 7.2     | 1960-71 | .42  | 10                 |
| Interior California sawmills and planing mills <sup>1/</sup>                         | 2421                         | $Y = 5.637 - 0.1468X$            | 223.6   | 1960-71 | .96  | 10                 |
| Coastal California sawmills and planing mills <sup>1/</sup>                          | 2421                         | $Y = 6.770 - 0.1335X$            | 66.6    | 1960-71 | .87  | 10                 |
| California pulp, paper, paperboard, and building paper <sup>2/</sup>                 | 2611<br>2621<br>2631<br>2661 | $Y = 17.858 - 1.1705X$           | 78.9    | 1960-71 | .93  | 10                 |
|                                                                                      |                              | $Y = 19.373 - 5.4774 \log X$     | 58.5    | 1960-71 | .86  | 10                 |
|                                                                                      |                              | $\log Y = 3.124 - 0.5329 \log X$ | 39.9    | 1960-71 | .80  | 10                 |
|                                                                                      |                              | $\log Y = 3.014 - 0.1196X$       | 110.4   | 1960-71 | .92  | 10                 |
| Seven selected California pulpmills and paper mills which consume wood <sup>2/</sup> |                              | $Y = 6.201 - 0.4290X$            | 73.6    | 1960-71 | .88  | 10                 |
|                                                                                      |                              | $Y = 6.781 - 2.0225 \log X$      | 61.3    | 1960-71 | .86  | 10                 |
|                                                                                      |                              | $\log Y = 2.103 - 0.5933 \log X$ | 39.7    | 1960-71 | .80  | 10                 |
|                                                                                      |                              | $\log Y = 1.978 - 0.1328X$       | 101.4   | 1960-71 | .91  | 10                 |

NOTE: Equations use natural logarithms (base e).

<sup>1/</sup> Y = Employees per million board feet, X = time (years).

<sup>2/</sup> Y = Employees per thousand bone-dry tons, X = time (years).





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1975. A technique and relationships for projections of employment in the Pacific coast forest products industries. USDA For. Serv. Res. Pap. PNW-189, 49 p., illus. Pacific Northwest Forest & Range Exp. Stn., Portland, Oreg.

Employment-wood consumption ratios vary by industry and region and change over time; they can be used to predict future employment in some sectors of the forest products industry, given estimates of future wood consumption. Past trends in total employment reflect the change in labor requirements and raw material input-product output. Seasonality of employment in forest industries varies by industry and region.

Keywords: Forest product industries, employment (forest labor), employment (seasonal).

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# INFLUENCE OF DATE OF CONE COLLECTION on Douglas-fir Seed Processing and Germination:



a case history

Donald L. Olson  
Roy R. Silen



## Abstract

Cones were harvested between August 12 and September 15, 1966, from 309 parent trees. Seed weights and germination rose sharply from August 12 to 25 and slowly thereafter. The early-picked lots required inordinate time in processing and special germination techniques and produced very ragged bed densities. Correlation between laboratory and nursery germination was 0.83, with field germination generally higher. Fully ripened cones picked in 1968 from the early-collected, low-germination trees of 1966 germinated normally.

KEYWORDS: Cone collection, germination (seed), seed weights.



The first implementation of the Progressive Tree Improvement Program<sup>1/</sup> was by the Crown Zellerbach Corporation<sup>2/</sup> at Vernonia, Oregon. Early phases of the program involved cone collection in 1966 from 309 individual parent Douglas-fir trees over a 35-day period and the growing of the seedling families in 1967 and 1968 in our experimental nursery at Corvallis, Oregon. The large number of parent trees provided us an excellent opportunity to document and evaluate all cone collection, seed processing, and nursery steps, the results of which are reported in this paper. Of all the factors that contributed to variation, seed immaturity arising from collecting cones too early has proved to contribute by far the most problems. It increased time required to process and use the seed and was a major contributor to variation in nursery bed density.

## Cone Collection and Seed Handling

The 309 parent trees were located in 35-year-old stands of the Oregon Coast Ranges along roads of the 80,000-acre Ed Stamm Tree Farm of the Crown Zellerbach Corporation surrounding Vernonia, Oregon. Elevations range from about 400 to 1,700 feet (130 to 550 meters). All bore one-half bushel (15 liters) or more of cones, resulting in a total collection of about 75 pounds (35 kilograms) of seed.

A half bushel or more of cones was collected from each tree for opera-

tional seedling production. A 1/4-bushel (2 gallon) sample was also collected for growing progeny test seedlings at Corvallis. The results of this paper pertain only to the 1/4-bushel samples, which averaged about 200 cones.

At cone-picking time, there was the serious problem of completing such a large collection in a short period of time. Because of the limited number of cone pickers, it was necessary to start picking as early as practical in order to finish before seedfall. Cone maturity was determined regularly from cone and embryo inspections from August 1 onward. Based upon embryo length and firmness of gametophytic tissue, cones were judged (inaccurately) to be mature enough on August 12 to start low elevation collections. Cone picking continued at a steady rate of about nine trees per working day which included most Saturdays and Sundays until the job was finished September 15. Cones were collected in numerical order starting with tree No. 1 and ending with tree No. 310 (with one tree skipped because squirrels had preempted the harvest). Hence, knowing the daily rate of collection, the actual date of collection for any tree could be determined with accuracy of a day or two. Even with this early start, the last collections were made in trees which were beginning to shed seed.

Cones were handled with more than the usual care in the field. The cones were stored briefly in large paper bags on a cement-floored garage in Vernonia. In order to assure good ventilation, at no time was one bag allowed to contact another bag. The cones were transported to Camas, Washington, whenever a pickup load had accumulated. There they were spread out on benches in a heated greenhouse for rapid drying. Even with such careful attention, many of the cones developed some mold. We had intended to prevent molding by getting cones rapidly into drying conditions, but handling so many parental lots overwhelmed the drying facilities and molds became a small but acceptable problem.

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<sup>1/</sup> Roy R. Silen. A simple, progressive, tree improvement program for Douglas-fir. USDA Forest Service Research Note PNW-45, 13 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1966.

<sup>2/</sup> Crown Zellerbach Corporation funded collection of data on parent trees, seed processing, and laboratory germination testing for the study. Special acknowledgment is given their forester, Richard Robertson, who made the special collection of seed in 1968 providing proof that low-germinating lots in original collection were normal in germination when collected in late September.



Some molding is practically unavoidable even in well-planned commercial collections during heavy seed years. When finally dry in November, the cones from the 309 1/4-bushel samples were transported to Corvallis. Seed processing was completed by late December. The entire cone handling procedure is comparable to conditions encountered with careful operational practice.

In order to maximize seed yield, the 1/4-bushel lots were processed with laboratory scale equipment. For tumbling, we used a 24-inch (0.6-meter) screen tumbler rotating at about 32 revolutions per minute. Seeds were then cleaned in a small, commercial air-screen seed cleaner. Seeds from this cleaner were given a final cleaning with desk top cleaner.<sup>3/</sup> Most lots were cleaned to practically 100-percent-full seed, but some lots dropped to 95-percent.

Complete records for each lot were made during cone and seed processing. Cones per bushel, seeds per cone, seed yield, trash content, and seed weight are summarized in table 1. In addi-

tion, the amount of mold, insect damage, and the extraction difficulty were rated (none, moderate, or severe). Percents by class are given in table 2.

Early in the processing it became obvious that seed yields in over one-quarter of the lots were poor because cones were not opening fully, or because the seeds were clinging tenaciously to the cone scales. A tabulation was made of causes for poor yield on the 75 poorest lots. In 36 lots (48 percent), seed was retained in the cone because scales failed to spread due to coneborer damage or mold. Of the 39 lots in which scales opened, seed was retained on the scales by midge in 16 lots (21 percent), by mold on 16 lots (21 percent), and by both insects and mold in 7 lots (9 percent). To increase seed yield, 32 of the 75 lots were soaked, dried, and retumbled. Seed yield from soaked cones was often greater than the initial yield.

## Seed Weights

The problem with early-picked cones was not detected until weights per 100 seed were calculated. Seventy-six percent of the lots collected before August 22 weighed less than

<sup>3/</sup> Roy R. Silen. A laboratory seed separator. *Forest Science* 10(2): 222-223. 1964.

Table 1.--Summary of data on cones and seeds from 309 parent trees at Vernonia, Oregon, 1966, covering collections, processing, and germination<sup>1/</sup>

| Measure                  | Number of cones per bushel | Cone cut index <sup>2/</sup> | Seed weight (grams per 100 seeds) | Trash (grams per 100 seeds) | Seeds per cone | Percent germination <sup>3/</sup> |           |
|--------------------------|----------------------------|------------------------------|-----------------------------------|-----------------------------|----------------|-----------------------------------|-----------|
|                          |                            |                              |                                   |                             |                | In vitro                          | Nursery   |
| Range                    | 344-1,784                  | 0.8-10.5                     | 0.549-1.437                       | 0.005-1.486                 | 3.9-53.7       | 0-94.0                            | 1.0-100.0 |
| Mean                     | 775.62                     | 5.631                        | 1.005                             | .094                        | 25.588         | 44.10                             | 52.78     |
| Standard deviation       | 196                        | 1.855                        | .185                              | .127                        | 9.318          | 27.48                             | 28.43     |
| Coefficient of variation | 25.3                       | 32.9                         | 18.4                              | <sup>4/</sup> 135.1         | 36.4           | 62.3                              | 53.9      |

<sup>1/</sup> A table of basic data on 309 trees is available on request to authors.

<sup>2/</sup> Number of filled seeds counted on face of longitudinally cut cone.

<sup>3/</sup> Oregon State University Seed Laboratory. Four lots of 50 seed. Does not include abnormal seedlings.

<sup>4/</sup> Distribution is highly skewed.

Table 2.--Percentage of lots by severity class with problems from mold and insects, and with seed extraction difficulties

| Severity class | Mold | Insects | Extraction difficulty |
|----------------|------|---------|-----------------------|
| Severe         | 17   | 17      | 26                    |
| Moderate       | 63   | 76      | 46                    |
| None           | 20   | 7       | 28                    |

0.90 gram per 100 seed. Lots collected after August 22 averaged 1.1 grams per 100 seed, and only 14 percent weighed less than 0.90 gram per 100 seed. The cone lots that failed

to open, or had appreciable mold, were found to be primarily from early-picked lots. In reviewing cone and seed processing time records, we found that these lots had required 3 to 10 times as much processing effort per unit weight of seed as the fully mature lots. They were tumbled longer, yielded less, and often required soaking, redrying, and more tumbling. Some cones had to be broken open by hand.

In figure 1, seed weight is plotted against collection date. An average weight for August 12 collections was 0.85 gram per 100 seed. For 10 days, seed weights were very low; then they climbed to about 1.05 grams, about a 20-percent rise for those seed collected about August 25, and rose gradually to average above 1.10 grams for collections

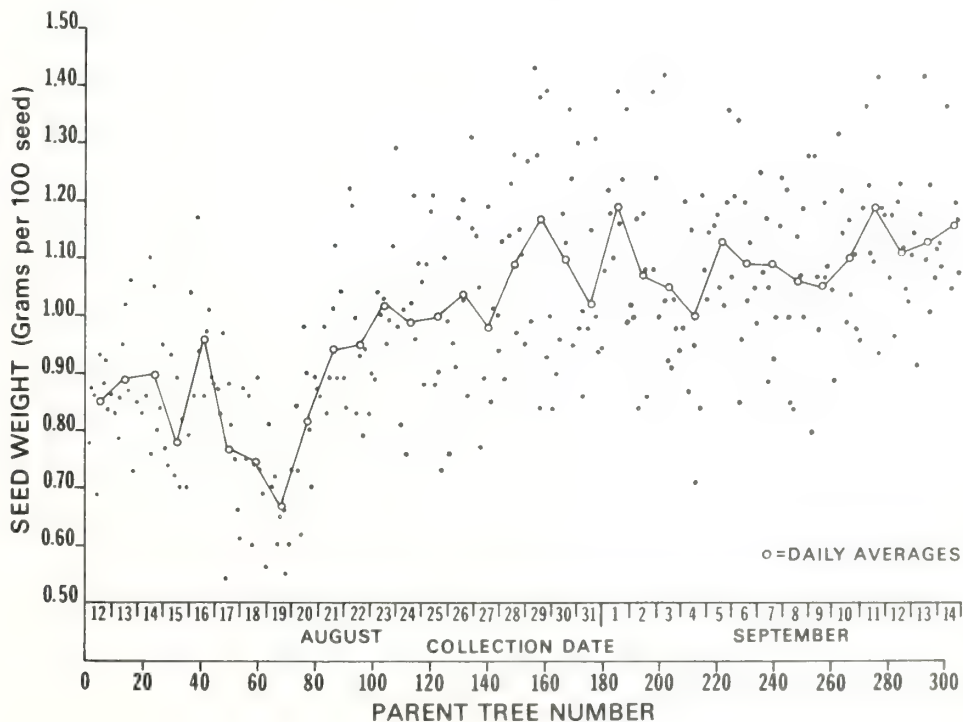


Figure 1.--Weight distribution of 100-seed collections for 309 parent trees by parent tree number and date of cone collection. Line connects daily seed-weight averages. Data show cones picked before August 26 as lighter than after this date. Distinctly lighter seed is seen for lots 40 to 75 collected about August 17-20, which originated 300 to 400 feet (90 to 120 meters) higher than trees picked earlier or later.

after September 1. But figure 1 also shows a very obvious dip to below 0.70 gram in the average weight in seed lots 40 to 75. The earliest collections in August were begun at about 1,000-foot (300-meter) elevation (lots 1 to 39), then the crew was moved to a 1,300-foot (400-meter) elevation (lots 40 to 75), and then back down to about 900-foot (275-meter) elevation for further collections. We hypothesized that this higher elevation collection was sufficiently less mature to be reflected in the seed weight. Subsequent observations of these immature lots revealed that they constituted the main source of serious problems with laboratory and field germination.

### Seed Weight-Yield Relationship

A regression analysis based on 309 seed lots summarized in table 1 confirmed suspected relationships. Seed weight increased linearly with collection date ( $r = +0.53$ ) and size of cone ( $r = +0.50$ ). Number of seeds per bushel of cones increased with number of seeds per cone ( $r = +0.80$ ) and number of cones per bushel ( $r = +0.29$ ) and decreased as more extraneous matter was included in the processed seed ( $r = -0.42$ ). The latter relationship resulted because poor-yielding lots were tumbled longer and, as a result, produced more broken bracts and small chips of stems and scales. As expected, number of cones per bushel dropped with increasing numbers of seeds per cone ( $r = -0.25$ ). Best seed yields were from fully ripened cones having a high number of seeds per cone, or from lots with lower seed numbers per cone but with more cones per bushel. No unexpected relationships developed, but the generally low correlation coefficients from so large a sample give a realistic indication of the variation in a single operational collection.

### Cutting Test Count vs. Seeds Per Cone

From each 1/4-bushel sample of undried cones, 10 cones were cut longitudinally for a record of the number of full seed seen on one cut surface. This is a standard cone testing procedure. A regression,  $\hat{Y} = 4.61 + 3.73X$ , expresses the relationship of this average seed count and actual seed yield per cone after processing for a parent tree (fig. 2). A rule-of-thumb using a multiplier of 4.5 (mean seed per cone divided by mean cut seed in table 1) for each cut seed gives a reasonably accurate yield estimate over most of the range of our data. Similarly, a multiplier of 3,500 per cut seed provides a rough estimate of number of seeds per bushel of cones.

Such multipliers, or regressions, could be greatly in error for single lots. For example, a cut cone count of 5 seed embraces a range of filled seed per cone of 10 to 40. Besides normal variation, this reflects extraction difficulties caused by mold, insects, and early collection. The relationships of cut test to average seed per cone ( $r = +0.74$ ) or to total seed in a lot ( $r = +0.62$ ) and weight of extraneous material ( $r = -0.31$ ), though highly significant, leave half or more of the variation in each unexplained.

### Laboratory Germination

All the lots were tested for germination by the Oregon State University Seed Laboratory. Only 200 seed from each lot were available for germination tests because many lots had low seed yield. A germination test with no prechill treatment<sup>4/</sup> was recommended by the laboratory for the freshly harvested seed. The 200 seed were

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<sup>4/</sup> Western Forest Tree Seed Council. Sampling and service testing, western conifer seeds. 1966.

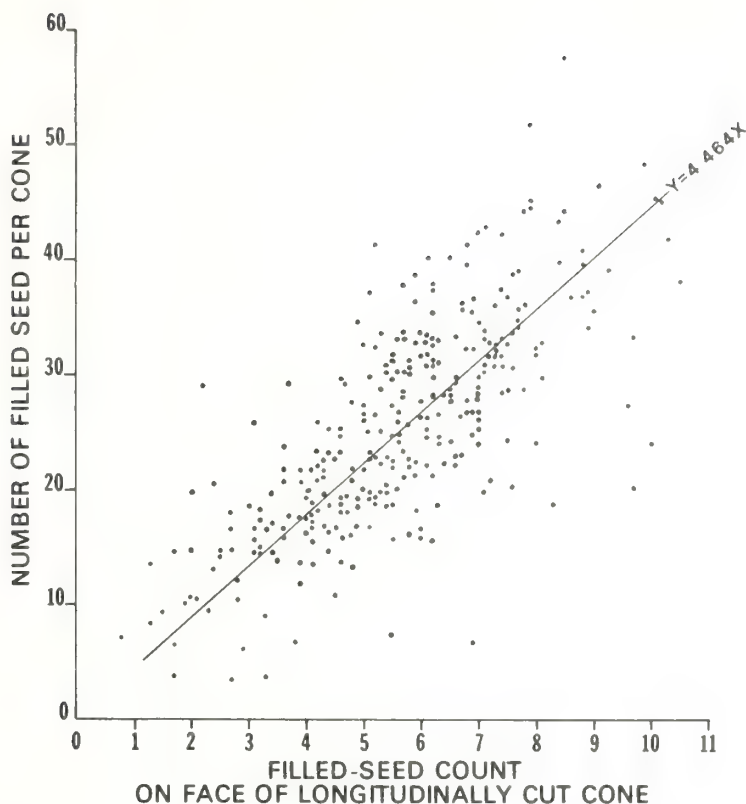


Figure 2.--Relationship of seed yield to filled seed count on face of a longitudinally cut cone.

divided between four germination dishes with 50 seed per dish. Summary of laboratory germination test means are also shown in table 1.

Germination figures from the OSU Seed Laboratory plotted against time of collection most vividly reveal the losses in early-picked cones (fig. 3A). In general, lots that were lightest in the early-picked group dropped in germination percent in an even more pronounced way than would be suspected from their lighter seed weights. Practically all the seed lots below 20 percent in laboratory germination were from parent trees 1-90. Only a few of the lots from parent trees 40 to 75, collected at 1,300-foot (400-meter) elevation, were above 10-percent germination.

## Nursery Germination

Effects of immature-seed collection were even more evident in the seedbed. The intent was to sow all the seed in our nursery beds at Corvallis. When estimates of expected seedling yields became available from laboratory germination test results, not enough filled seed remained in 40 of the 1/4-bushel lots to produce the 150 seedlings desired for progeny tests. We decided the maximum number of seedlings would be best obtained if the 40 lots (34 of the 40 being among parents 1 to 90) were germinated in the laboratory and then planted in the beds as germinants. When we germinated this seed in a perlite medium, we had another disaster. Bacteria killed the growing points of emerging hypocotyls. Despite the use of Phygon on the seed after stratification and Terramycin



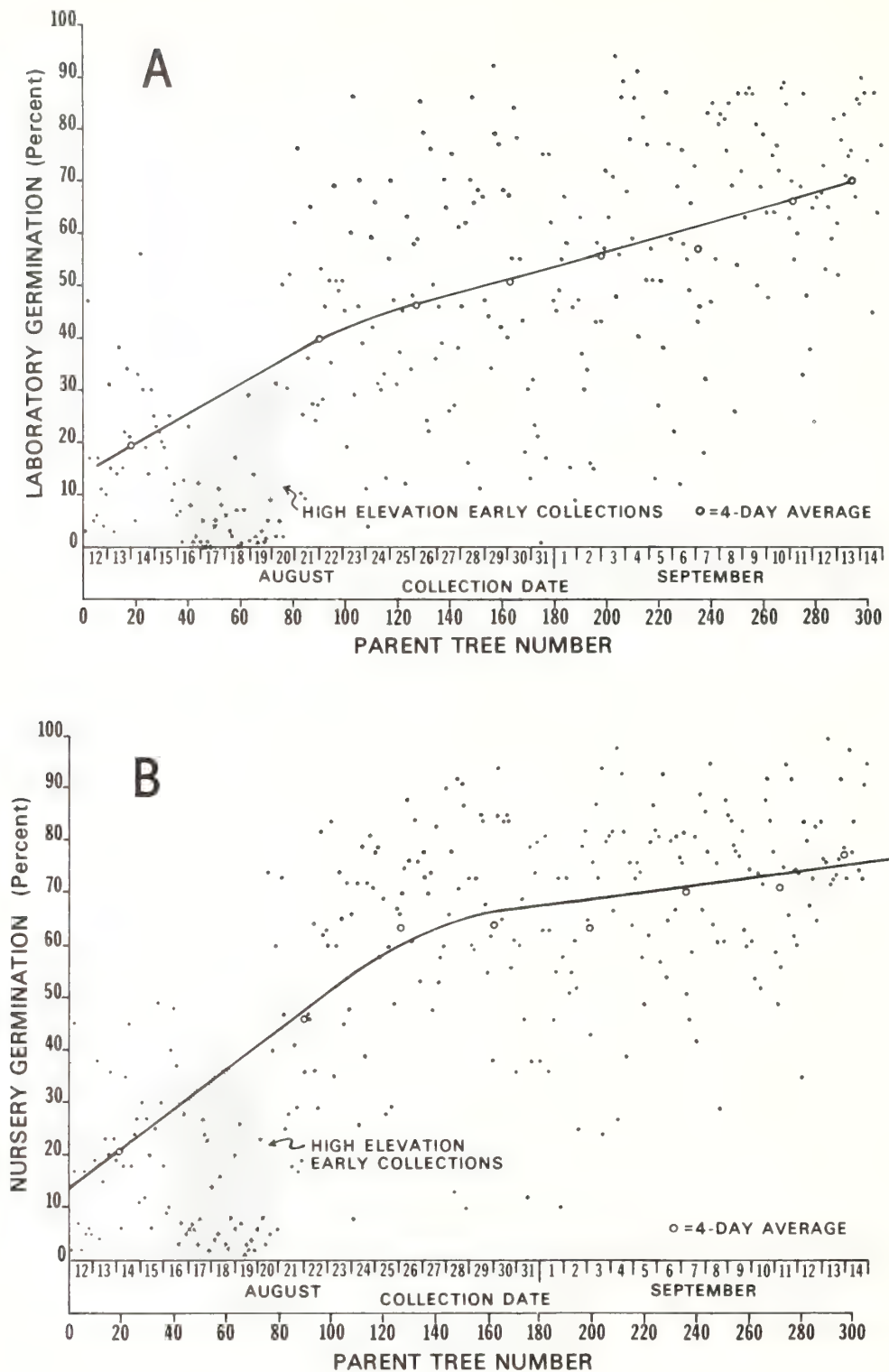


Figure 3.--Laboratory (A) and field (B) germination percent of seed from 309 parents by collection date. Freehand curves of average germination exclude data of parent numbers 40 to 75 in the shaded area.



in the perlite, seedling losses were severe. Further unsuccessful germination attempts in other media resulted in loss of much of the badly needed seed. We finally found that a germination medium of pure peat moss would completely prevent bacteria losses, producing healthy germinants, but not in time to assure 150 germinants from seed remaining in 8 of the 309 lots.

Seed of the remaining 269 lots having ample seed (309 minus 40) were sown in nursery beds. Laboratory germination test results were used to adjust the amount of seed sown per 4-foot row to produce a row of about 40 plants. An estimate of nursery germination was made in June by counting seedlings that appeared above soil surface. Such an estimate is conservative, since seeds that germinate but do not emerge above the surface are not included. A high variation was observed between laboratory and field germination. Some lots with laboratory germination estimated below 30 percent had excellent field germination to produce overstocked rows. Others, including some with high estimates of laboratory germination percent, germinated poorly in the beds to give poorly stocked rows.

Percent of nursery germination is displayed by collection date in figure 3B. Germination of the 40 lots given special treatment is also included. In figure 3 poorly germinating seeds from higher elevation (parents 40-75) are shaded to remove them from the remaining data. Doing so results in a smooth curve of average germination over time. The nursery germination curve is the more readily interpreted in terms of seed ripening. Germination percent rose rapidly from about 15 percent for August 12 seed to 60 percent for August 26 seed. Enough lots were still requiring additional ripening after August 26 to provide for another 15-percent rise by September 15 when seedfall began. Laboratory germination showed greater

variation and a more gradual rise through the entire period. Since laboratory germination on fresh seed without stratification was consistently lower, these lots may have benefited from the stratification used before nursery sowing. Even so, laboratory and field germination were not well correlated, as seen in figure 4. The coefficient of correlation  $r$  is 0.83, indicating only 69 percent of the variation explained by the relationship.

Figure 5 shows most dramatically the overall effects of the early-picked lots on nursery bed stocking. It is a vertical mosaic of two portions of one replication of our seedbeds at Corvallis. Each row has seedlings from a single parent. We purposely sowed this one replication in the order that cones were collected, i.e., in consecutive numerical order from parent trees 1 to 310. Rows 91 to 309 from parent trees collected later than August 26 (partly shown in figure 5B) were quite uniform in germination. In contrast, rows for parent trees 1 to 90, which were collected from August 12 to August 26, are very spotty in germination (figure 5A). These rows had known low germination, so most were sown with over 600 filled seed per row. Many more and even larger gaps would have shown in the photograph had not 34 seed lots with lower germination been grown elsewhere with special treatment.

Average field germination of the fully ripe lots (parent trees 150 to 300) was nearly 70 percent. In this group, 88 percent of all the lots germinated above 50 percent. As a practical conclusion, it is apparent that any lot of fully ripe seed comprised of several parent trees, handled well and uniformly sown, should have eliminated most problems leading to uneven seedbed densities. On an individual parent basis, our bed densities in lots 150 to 300 benefited somewhat because we adjusted sowing rates to reflect laboratory germination differences rather than sowing the same number of seed per row.

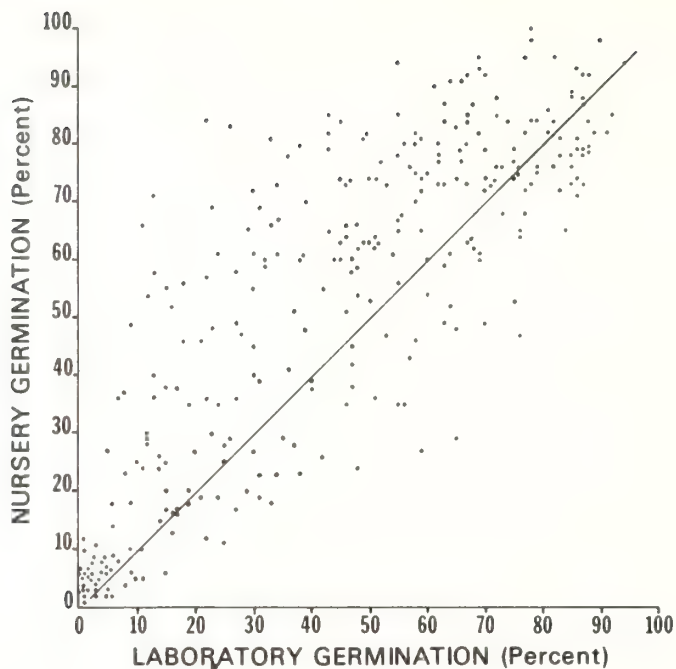


Figure 4.--Field versus laboratory germination percent. Line shows expected 1:1 relationship. Field germination was generally better than predicted from laboratory germination.

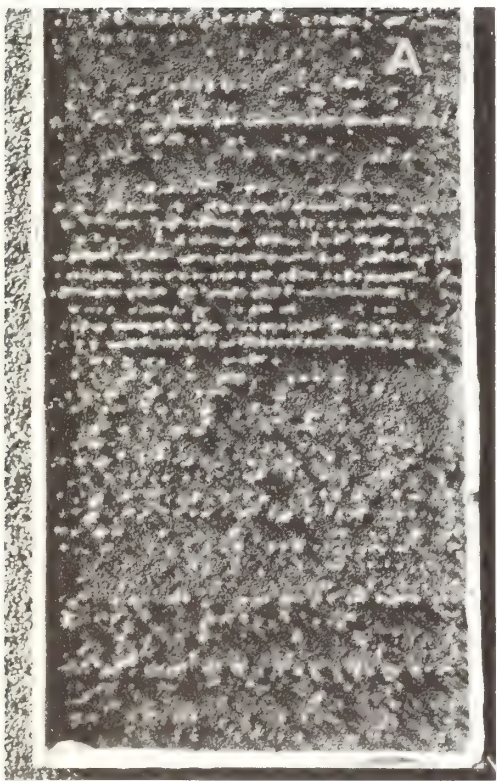
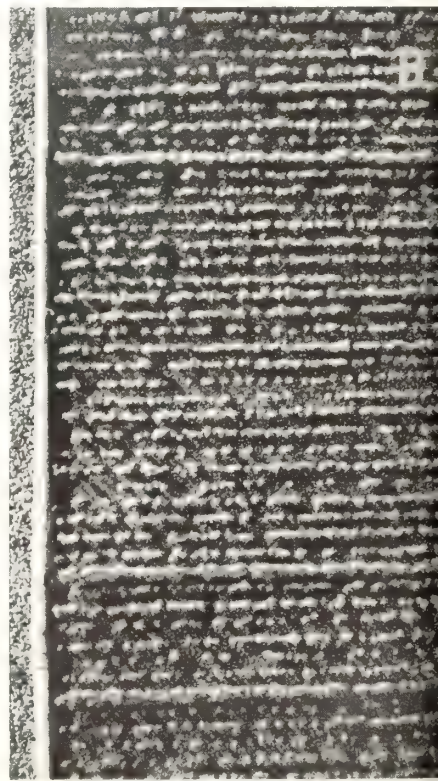


Figure 5.--Low seedbed densities from early-picked (A) cones contrasted with high densities from fully-ripened cones (B). Each row in (A) represents a single parent's seed from collections made between August 12 and August 20. (B) represents seed collections between September 5 and September 10. Overly dense rows result from dense sowing of seed thought to have poor germinability based upon laboratory germination test.



## Retrial With Fully Ripened Seed

Evidence was sought that parent trees showing low germination from early collections in 1966 were otherwise normal. In September 1968, during another good seed year, cones were collected from 13 parent trees. All 13 were from the group picked before August 25 in 1966, which had averaged only 6-percent nursery germination that year. A new nursery germination count on 1968 seed based upon three rows of 200 seeds per parent averaged a normal 72 percent (table 3), a figure corresponding well to the germination percent of fully ripened seed in 1966 (fig. 3B).

Table 3.--*Comparison of nursery germination of 1966 and 1968 seed collected from 13 of the parent trees showing low 1966 germination. The 72-percent average germination in 1968 is evidence that low germination of 1966 was due to early collection*

| Parent number | Nursery germination percent |                         |
|---------------|-----------------------------|-------------------------|
|               | 1968 seed <sup>1/</sup>     | 1966 seed <sup>2/</sup> |
| 1             | 74                          | 2                       |
| 5             | 22                          | 2                       |
| 17            | 86                          | 23                      |
| 27            | 45                          | 11                      |
| 42            | 81                          | 3                       |
| 49            | 99                          | 3                       |
| 61            | 61                          | 3                       |
| 63            | 98                          | 20                      |
| 67            | 98                          | 1                       |
| 69            | 88                          | 2                       |
| 71            | 58                          | 2                       |
| 74            | 82                          | 8                       |
| 75            | 46                          | 3                       |
| Average       | 72                          | 6                       |

<sup>1/</sup> Based upon 600 sown seed.

<sup>2/</sup> Based upon 385 to 4,339 sown seed.

## Discussion

The need to begin cone collections early arises whenever large numbers of trees must be covered with limited manpower. The true cost of including a portion of immature seed in a collection is not well documented. This case history furnishes a particularly complete documentation because records of seed from each parent could be followed through all extraction, germination, and nursery steps. With 309 parent trees, much of the data can be considered applicable to operational collections. It also provides sound averages and the magnitude of normal variations from the average. The collection year, 1966, was typical of an excellent seed year in all regards with most trees flowering, a good pollination, and generally high seed yields. Lots collected the 10 days before seedfall showed less mold, required minimal effort to process cones and seed, germinated well in nursery beds, and produced excellent plants.

Those lots harvested the first 10 days (before August 23) required several fold efforts in seed extraction and germination, produced very light seed, contained nearly all the lots germinating below 10 percent, suffered heavily from loss after germination, required inordinate efforts to produce enough seedlings for a progeny test, and were the major cause of poor seedbed densities. On a per-seedling basis, at least 10 times the effort was required compared with cone collections made within 10 days of seedfall. Although such comparisons are inexact, they serve to place a better perspective on the true cost of immature seed.

Several alternatives are open to reduce such costs. Seed lots suspected of immaturity may be artificially ripened. Such lots may also be discarded or used only when other seed is exhausted. The obviously better answer is to avoid these problems by providing ample effort to collect only mature cones.



The case history has provided an index to convert the cone cut test to seeds per cone or seeds per bushel. The index should not be used without inspection of the large variation associated with any filled seed count (fig. 2).

Several further observations appear important. Seed averaging below 0.80 gram per 100-seed weight were predominantly from immature lots, and fully ripened lots averaged well above 1.0 gram per 100 seed. Low seed weights thus provide a first clue to immaturity that should become cause to check for other signs such as low germination, bacterial attack of growing points following germination, and low seedbed densities. However, light seed may only indicate small but well-ripened seed.

The inexact correspondence between laboratory and nursery germina-

tion, with nursery germination the higher, was not expected. Much of this variation may have been due to need to stratify fresh seed for the germination test, not considered necessary in this instance. However, the factors involved in the rather large discrepancies in many lots need more investigation.

Of subtle importance is the observation from figures 1 and 3B that seed weight and nursery germination continue to improve steadily for collections made even during the last 2 weeks before seedfall. This suggests that even as seed begins to fall from some trees, on other trees cones are still maturing. The importance may be minor with operational collections. However, with collections intended for genetic testing, such differences in maturity between trees on the same date could lead to nongenetic factors being incorporated into the tests.

Olson, Donald L., and Roy R. Silen

1975. Influence of date of cone collection on Douglas-fir seed processing and germination: a case history. USDA For. Serv. Res. Pap. PNW-190, 10 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Cones, seeds, and seedlings from 70 of 309 parent trees were collected too early, resulting in poor cone yields, reduced seed weight, poor germination, bacterial susceptibility, reduced seedbed density, and greater expenditure of time.

KEYWORDS: Cone collection, germination (seed), seed weights.

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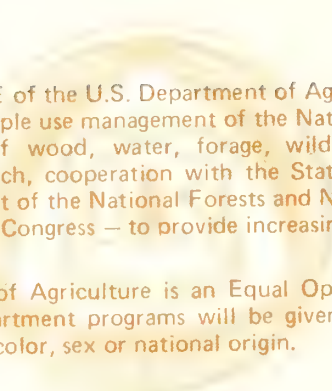
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# Seed Production of Central Oregon Ponderosa and Lodgepole Pines

Walter G. Dahms  
James W. Barrett

## Abstract

Seed production estimates for central Oregon ponderosa and lodgepole pines over periods ranging from 11 to 22 years indicate enough lodgepole pine seeds were produced to provide for a satisfactory crop of seedlings 3 years out of 4 if other conditions were favorable. Ponderosa pine produced only five good seed crops during a 22-year period. Number of sound seeds produced was estimated from seed trap catches. Percent of seeds that were sound was estimated from a cutting test.

KEYWORDS: Seed production, ponderosa pine, *Pinus ponderosa*, lodgepole pine, *Pinus contorta*.



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## Introduction

Seed production and dissemination data are necessary for planning natural regeneration of any forest. This kind of information is especially needed for central Oregon lodgepole pine (*Pinus contorta*) because, unlike the Rocky Mountain variety, cones are generally not serotinous and seeds are shed within the first year after cone maturation (Critchfield 1957, Mowat 1960, Trappe and Harris 1958). Furthermore, central Oregon lodgepole pine stands are normally regenerated by natural means, usually shelterwood. The present desire to maintain a continuous forest cover also makes the shelterwood or seed tree method an attractive approach to regenerating even-aged ponderosa pine (*Pinus ponderosa*) stands and increases interest in frequency and size of ponderosa pine seed crops.

To acquire the needed information on size and frequency of seed crops produced by these two pines, studies were begun in central Oregon during 1953. Partial results have been presented by Barrett (1966) and Dahms (1963). This paper contains final results from these studies plus a brief review of the most pertinent literature concerning seed production and its dissemination for ponderosa and lodgepole pines.

## Review of Past Work

Lodgepole pine is a prolific seed producer according to Tackle (1965). Good crops are borne at 1- to 3-year intervals with light crops during intervening years. However, average annual seed production varies substantially from place to place and from year to year. Bates (1930), for example, reports an average annual pro-

duction of 72,992 good<sup>1/</sup> lodgepole pine seeds per acre<sup>2/</sup> on the Medicine Bow National Forest in Wyoming over a 10-year period. None of the crops during this 10-year period reached 200,000 seeds per acre, but only 1 year was a complete blank. During the same 10-year period, the average annual seed production was 320,053 sound seeds per acre on the Gunnison area in Colorado (Bates 1930). During 5 of the 10 years on the Gunnison National Forest study area, there were 200,000 or more seeds per acre and during a 6th year almost that many. During 1 year, more than 800,000 sound seeds per acre were produced. Less than 100,000 seeds per acre were produced during each of the remaining 4 years, but there were no complete blanks. Montana results reported by Boe (1956) indicated an average annual seedfall of 17,500 sound seeds per acre over a 4-year period.

Ponderosa pine produces fewer seeds per crop and fewer good crops than lodgepole pine. Fowells and Schubert (1956) reported 200 or more cones per acre produced 4 years out of 16 in the west side Sierra subregion of California. However, during 7 of the 16 years, less than 50 cones per acre were produced. In terms of number of seeds per acre, this means less than 2,000 sound seeds 7 years out of 16 and a maximum crop of less than 20,000 sound seeds per acre for the best year.

Shearer and Schmidt (1970) reported only two good crops and one fair crop of ponderosa pine seed in western Montana during the 11-year period from 1948 through 1958. The best crop (1958) averaged 135,000 seeds per acre, but the fair crop

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<sup>1/</sup> Good seeds as used by Bates means seeds that will germinate under the conditions of a laboratory germination test.

<sup>2/</sup> One acre equals 0.404687 of a hectare.

consisted of only 42,000 seeds per acre. During 3 of the 11 years, no seeds were caught; and on 2 other years, less than 500 seeds per acre were found. Curtis and Foiles (1961) reported three bumper seed crops in central Idaho during the 23-year period from 1936 through 1958. During each of the heavy seed years, more than 200,000 ponderosa pine seeds per acre were produced.

Larger, more vigorous trees of both lodgepole and ponderosa pines produce the most seeds. Bates (1930) divided lodgepole pine trees into dominant, codominant, intermediate, oppressed, and suppressed tree classes, with crowns within each tree class divided into full, average, and small classes. There was a general trend of lesser production from dominant to suppressed trees and from full to small crowns. However, Bates did not consider the trend as strong for lodgepole pine as for some other species.

Dominant ponderosa pine trees accounted for by far the largest share of cones produced by this species (at least 97 percent). Codominants accounted for only 1 to 1.5 percent of all cones produced, while the intermediate and suppressed crown classes accounted for only a fraction of 1 percent of the total (Fowells and Schubert 1956).

Despite the fact that dominant trees accounted for most of the cones produced in Fowells and Schubert's study, not all dominants were seed producers. Among the dominants, the largest crowned, most vigorous trees were the best producers. Size and frequency of cone crops were both correlated with tree diameter. Dominant trees in the 7.6- to 11.5-inch<sup>3/</sup> diameter class averaged only 1 crop in 16 years, while dominant trees larger

than 24 inches averaged 10 crops in 16 years.

Foiles and Curtis (1973) presented results from central Idaho that tended to confirm some of Fowells and Schubert's California results. Mature Idaho trees produced more seed than immature trees, and isolated individuals produced better than stand-grown trees.

Percent of seed that was sound was highest during years of heavy seed production and there was also a tendency for sound seeds to fall earlier in the season, according to both Fowells and Schubert (1956) and Shearer and Schmidt (1970).

Seed from ponderosa pine generally falls during late summer and early fall. Curtis and Foiles (1961) reported that the 1958 crop in central Idaho began falling by August 12 and that maximum seedfall occurred between September 10 and 30. They also reported that some seedfall continued through the winter. Fowells and Schubert (1956) reported that seedfall generally occurred during the autumn months. Not all seeds are shed at that time, however. In one instance when traps were left out all winter at Blacks Mountain, only 67 percent of the seed had fallen by the end of November. In another instance on the Stanislaus National Forest, they reported 84 percent had fallen by November. Mowat (1960) reported that by October 22 at elevations up to 5,400 feet<sup>4/</sup> most of the lodgepole pine seeds of the 1954 crop in central Oregon had been shed; but at 5,900 feet, up to 25 percent of the seeds remained in the cones.

Weather obviously had important effects on the development of cone crops; but not all of the relationships are clear, according to Fowells and Schubert (1956). They

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<sup>3/</sup> One inch equals 2.54 centimeters.

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<sup>4/</sup> One foot equals 0.304801 of a meter.



noted that white fir cone crops were adversely affected by frost during the flowering period. However, they were inclined to believe that the pines were not subject to frost damage in California because of late flowering, citing a study by Roeser (1941) to substantiate their belief. Frost, on the other hand, was cited as the probable reason for failure of the 1919 lodgepole pine seed crop on the Medicine Bow National Forest, while the same year a bumper crop was produced on the Gunnison National Forest in Colorado (Bates 1930).

Sorensen and Miles (1974) cited definite evidence of frost injury to developing conelets of both ponderosa and lodgepole pines in the central Oregon area. Ponderosa pine was much more severely damaged than lodgepole. They suggested differential frost resistance of conelets of the two pines was probably another mechanism favoring lodgepole pine over ponderosa pine in frost pocket situations.

Freezing damage to lodgepole pine conelets in an area where lodgepole and ponderosa pines grow together suggests that damage might frequently be severe in frost pocket situations where only lodgepole pine can survive. It may well turn out that basin or frost pocket areas on central Oregon pumice are difficult to regenerate not only because of germination and seedling survival problems but also because lodgepole pine seed crops may be less frequent and smaller in size. Cochran<sup>5/</sup> and other foresters believe they see less frequent cone crops in frost pocket situations.

Pine seeds are not dispersed in substantial numbers very far from the tree that produced them. For example, Boe

(1956) reported that number of lodgepole pine seeds dispersed 1 chain<sup>6/</sup> out into a clearcut was only 14.3 percent of the number that fell under the timber. At 2 or 3 chains, only 8.6 percent of the under-timber-catch was found.

Barrett (1966) found that ponderosa pine seeds at 2 chains represented 24.6 percent of those caught at timber edge and at 6 chains, 7.5 percent. It is probable that Barrett's "at timber edge" and Boe's "under the timber" are not entirely comparable.

## Study Methods

There were two studies, one at Pringle Falls Experimental Forest and the other on the Winema National Forest just east of Crater Lake National Park. At both locations, traps were used to catch seeds and thus provide estimates of number of seeds reaching the ground. Cutting tests were used to distinguish sound seeds from nonsound.

The Pringle Falls study was begun in 1953.<sup>7/</sup> A mature ponderosa pine stand, an immature, even-aged ponderosa pine stand (age 100 years in 1953), and a mature lodgepole pine stand were sampled--10 traps, each 2 by 3 feet, in the mature ponderosa pine stand, 5 in the immature stand, and 5 in the lodgepole pine stand. Later (1966) an additional five traps were added in the immature ponderosa pine. Seed traps were mechanically spaced along a straight line in each of the three stands. The goal of this study was to estimate size and frequency of seed crops for ponderosa and lodgepole pines.

The lodgepole pine seed traps were

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<sup>6/</sup> One chain = 20.1168 meters.

<sup>7/</sup> This study was designed, installed, and maintained by Edwin L. Mowat until his retirement in 1963.

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<sup>5/</sup> Personal communication with P. H. Cochran, soil scientist, Silviculture Laboratory, Bend, Oregon.



located in a nearly pure lodgepole pine stand in a *Pinus contorta*/*Purshia tridentata* community growing in the Pringle Falls Research Natural Area. Other plants found in the sparse understory include western needlegrass (*Stipa occidentalis*), Ross's sedge (*Carex rossii*), bottlebrush squirrel-tail (*Sitanion hystrix*), and strawberry (*Fragaria sub-jibbula*) (Franklin et al. 1972). Elevation is about 4,300 feet.

The old-growth ponderosa pine sampled for seedfall was also located in the Pringle Falls Research Natural Area. Traps were located in a *Pinus ponderosa*/*Purshia tridentata* plant community at an elevation of 4,500 feet.

The ponderosa pine seed traps in the young-growth stand are located in a *Pinus ponderosa*/*Ceanothus velutinus* community on the Lookout Mountain addition to the Pringle Falls Experimental Forest. This is a seral community growing on an *Abies concolor*/*Ceanothus velutinus* climax association. Elevation is 4,700 to 5,000 feet.

The Winema lodgepole pine seedfall study, started in 1959, was aimed more at estimating dispersal of seed into clear-cut areas from surrounding timber edges. Lines of seed traps started 1 chain from the timber edge under the timber and extended into a clearcut area at 1, 3, 5, and 7 chains from timber edge in nearly north, south, east, or west directions. A given line of traps consisted of 4 traps under the timber and 4 others at the 1-, 3-, 5-, and 7-chain distances into a clearcut for a total of 20 traps per line. From 4 to 6 such lines were operated during the 11 years the study was in operation, except 1959 when only 16 traps were used.

The Winema study was located in a

predominantly mature lodgepole pine stand growing in a *Pinus contorta*/*Purshia tridentata*-*Ribes cereum* plant community.

## Results

### PRINGLE FALLS STUDY

#### Size and Frequency of Crops

Lodgepole pine definitely produced larger and more frequent seed crops than ponderosa pine (fig. 1) at Pringle Falls. During the 16 years with available records from 1953 through 1971, lodgepole pine produced nine crops with 200,000 sound<sup>8/</sup> seeds per acre or more. The largest crop was in 1954 when an estimated 900,000 sound seeds per acre were produced. There were only 3 years during the period when less than 50,000 seeds per acre were produced, and no total failures.

The old-growth ponderosa pine in contrast produced only three measured crops of 200,000 seeds per acre or more for certain during the 19-year period from 1953 through 1971. However, 1968, a known good seed year, also probably exceeded 200,000 (fig. 2); but the records were destroyed. A fifth good crop (1974) also appears assured. Thus during the 22-year period 1953 through 1974, there were five good ponderosa pine seed crops.

Differences between old-growth and young-growth ponderosa pine seed production were minor and almost certainly could be accounted for by sampling variation. The largest seed crop produced by the immature stand was 663,000 sound seeds per acre. Good seed crops occurred in both old-growth and immature stands the same years.

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<sup>8/</sup> As determined by a cutting test of all seeds that looked at all normal. This is undoubtedly an overestimate of the number of seeds that will germinate.

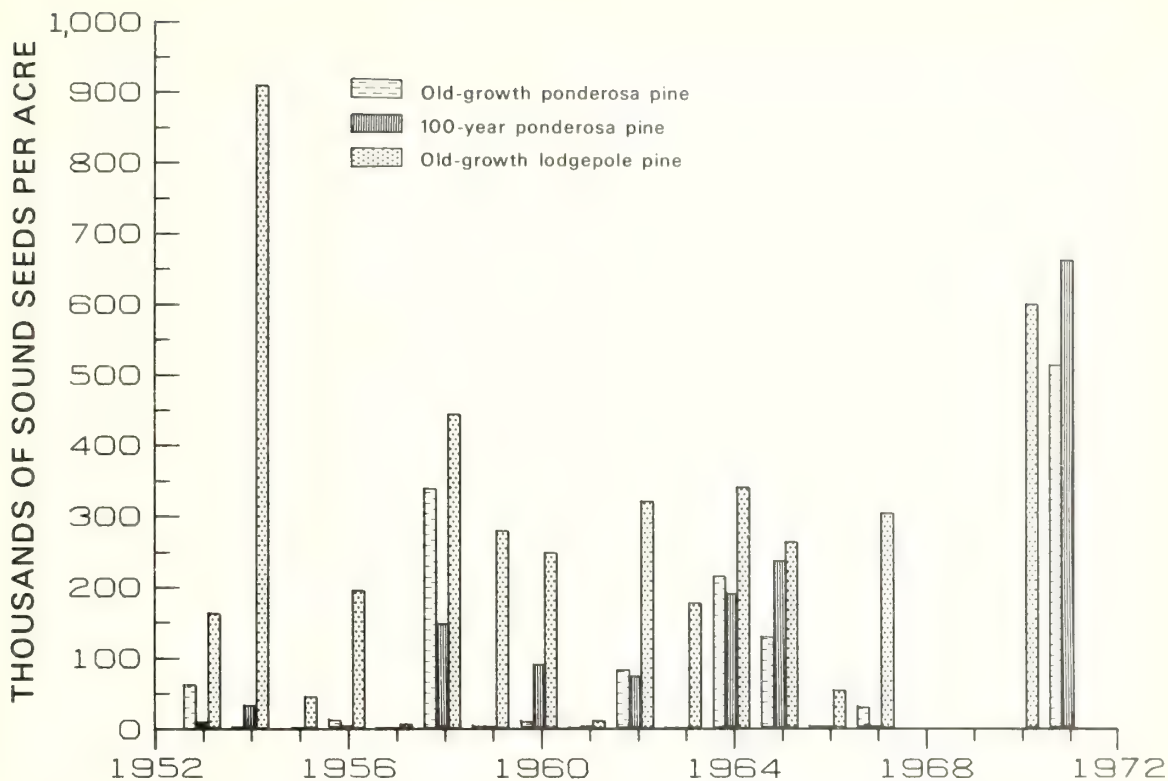


Figure 1.--Sound seeds per acre by year for old-growth ponderosa pine, 100-year ponderosa pine, and old-growth lodgepole pine. Pringle Falls study (data missing for 1968, 1969, 1970, and 1971 were destroyed by the 1974 fire at the Silviculture Laboratory in Bend).

Figure 2.--These 5-year-old seedlings on Pringle Butte originated from the 1968 seed crop. Although no records remain to show size of that crop, the resulting seedling catch on this 19-acre clearcut clearly demonstrates the 1968 seed crop was a substantial one. Site preparation, done in the early spring of 1969 as a prelude to planting, apparently buried many seeds to about the right depth. Logging in late winter (early 1969) meant seeds from all of the trees growing on the area had been showered down on the clearcut patch prior to cutting.

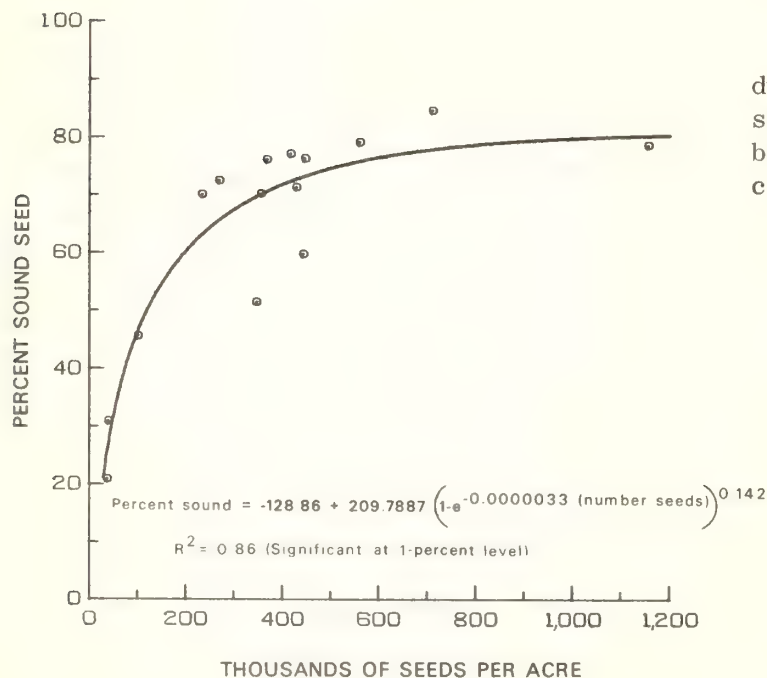


## Time of Seedfall

Lodgepole pine seedfall was 46 percent complete by early October. An additional 29 percent was released by early November, and the remaining 25 percent came down by the following summer.<sup>9/</sup> There are some substantial deviations from the average figures during individual years. For example, seeds were 89 percent shed by October 9 in 1960, but only 14 percent shed by October 1 in 1959, both good seed years.

Ponderosa pine did not, on the average, release its seed quite as early as lodgepole pine. Of the seed produced by the old-growth and immature stands, 38 and 39 percent, respectively, had been shed by early October. An additional 44 percent was shed by early November. Between early November and summer, 18 and 17

<sup>9/</sup> These figures are based on total seedfall for all of the years involved. Consequently the average is weighted in favor of the heavy seed crops as it should be.



percent of seed from old-growth and immature stands came down. These average figures might seem comforting to someone who would like to do a site preparation job with fire in late September or even early October. However, there is a great deal of variation about the average. By October 7, for example, 89 percent of the large 1958 crop had been shed.

## Soundness of Seed

Lodgepole pine seed averaged 74.7 percent sound on the basis of a cutting test. There was a tendency for a higher percentage of seeds to be sound during the fall season when seedfall is normally heaviest. Seed that had fallen by early October was 75.5 percent sound, that which fell in October and early November was 73.0 percent sound, but that which fell during the following winter, spring, and early summer was only 55.2 percent sound. These findings tend to agree with results published earlier by other investigators (Fowells and Schubert 1956, Shearer and Schmidt 1970).

Sound seed percentage was also greater during years of abundant lodgepole pine seed production (fig. 3). The relationship between soundness of seed and size of seed crop is significant well beyond the 1-percent

Figure 3.--Percent of seeds that were sound as related to crop size. Lodgepole pine, Pringle Falls Research Natural Area.



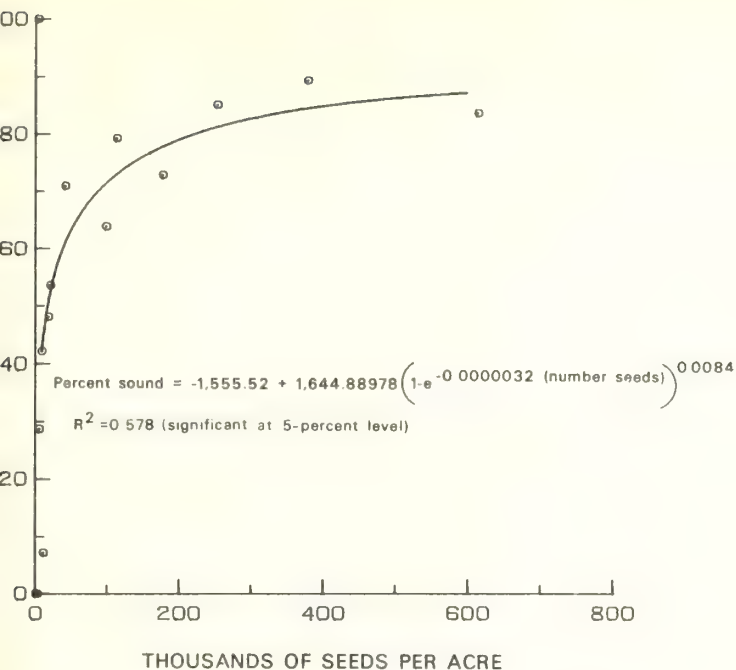


Figure 4.--Percent of seed that was sound as related to crop size. Old-growth Ponderosa pine, Pringle Falls Research Natural Area.

level. None of the crops with 100,000 seeds per acre or less averaged 50 percent sound. All of the larger crops were more than 50 percent sound.

Ponderosa pine seed produced by the old-growth stand averaged 80.8 percent sound and that from the immature stand, 86.6 percent. Soundness also tended to relate to time of seedfall and size of crop, as was also true of lodgepole pine seed; but the relationships were not quite so strong. Seeds shed by early October in the old-growth stand were 84.3 percent sound, those shed between early October and early November were 83.7 percent sound, and those falling between early November and the following late spring or summer were 68.6 percent sound. Percents of seeds that were sound from the immature stand were 85.9, 91.4, and 78.1 for equivalent periods. Sampling variation almost certainly can account for the differences between the two stands.

There is a significant relationship between total number of seeds produced and percent sound in the case of the old-growth stand (fig. 4). However, in the case of the immature stand, no relationship could be demonstrated.

## WINEMA STUDY

### Size and Frequency of Crops

Lodgepole pine produced five crops of 200,000 or more sound seeds per acre on the Winema study area during the 11-year period from 1959 through 1969 inclusive. The largest crop was in 1962 when an estimated 854,500 sound seeds per acre were produced. Two crops, 1961 and 1966, consisted of an estimated 14,000 and 14,300 sound seeds per acre. The remaining 4 crops ranged from 56,600 sound seeds in 1967 to 178,200 per acre in 1959 (fig. 5).

Size of seed crops at Pringle Falls and on the Winema National Forest were correlated to a considerable extent. Seed crops at both locations were near failures in 1961 and 1966. However, in 1962 the largest crop of all on the Winema (854,500 sound seeds) was matched by only about 320,000 sound seeds at Pringle Falls.

### Time of Seedfall

The largest percentage of seeds fell during October and early November. Overall, 36.9 percent had fallen by early October, an additional 40.8 percent fell

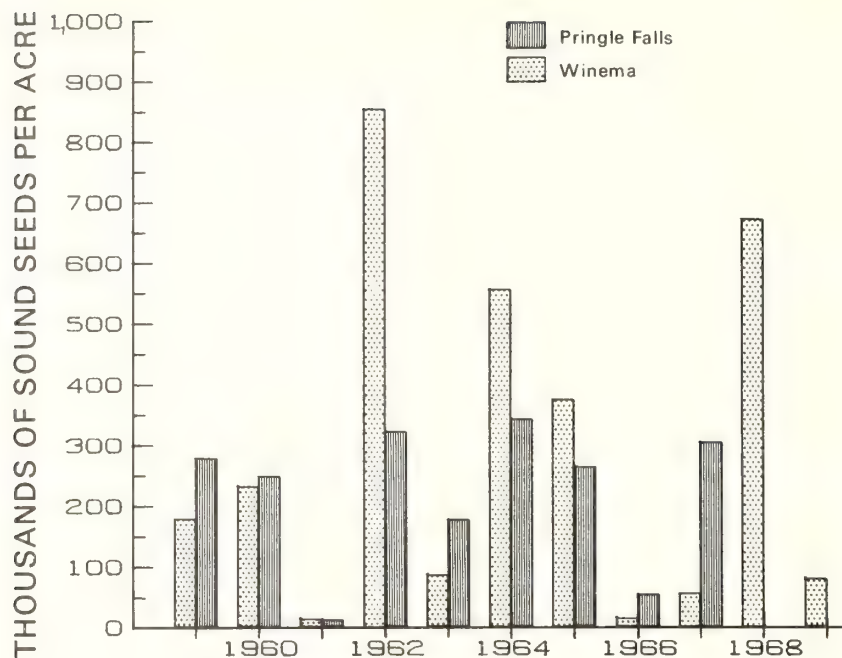


Figure 5.--Number of sound Lodgepole pine seeds per acre on the Winema and Pringle Falls areas.

by early November, and the remaining 22.3 percent fell by the following summer.

There was considerable variation in time of seedfall from year to year. The bumper crop of 1962 was only 5.5 percent down by early October; but in the case of the second largest crop, 1968, 65.8 percent had fallen by the same date.

Seedfall on the Winema area was slightly behind that at Pringle Falls. The greater elevation of the Winema area, about 5,000 feet as compared to about 4,300 feet at Pringle Falls, could reasonably account for the difference.

### Soundness of Seed

The Winema lodgepole pine seed averaged 79.3 percent sound overall, compared with 74.7 at Pringle Falls, but there was considerable variation from year to year.

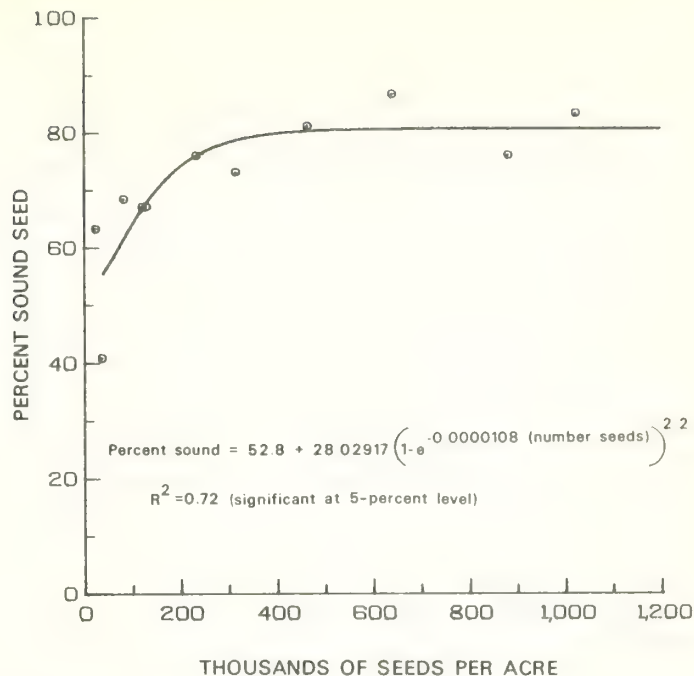
The range was from 40.1 percent sound in 1966 to 86.7 percent in 1964. Consequently, differences between the two areas are reasonable.

There was a definite tendency for percentage of seeds that were sound to be higher when a larger crop of cones was produced (fig. 6). The correlation between percent sound and size of crop is statistically significant at the 5-percent level.

Percentage of seeds that were sound was higher from the October and November collection dates than from the summer collection. Seeds averaged 78.3, 84.4, and 72.6 percent, respectively, for the three collection dates. Although the differences do not seem large, seeds from the summer collection had a lower percentage of seeds that were sound than from either the early or late fall dates every



Figure 6.--Percent of seed that was sound as related to crop size. Lodgepole pine, Winema study.



one of the 11 years, convincing evidence that there is a difference.

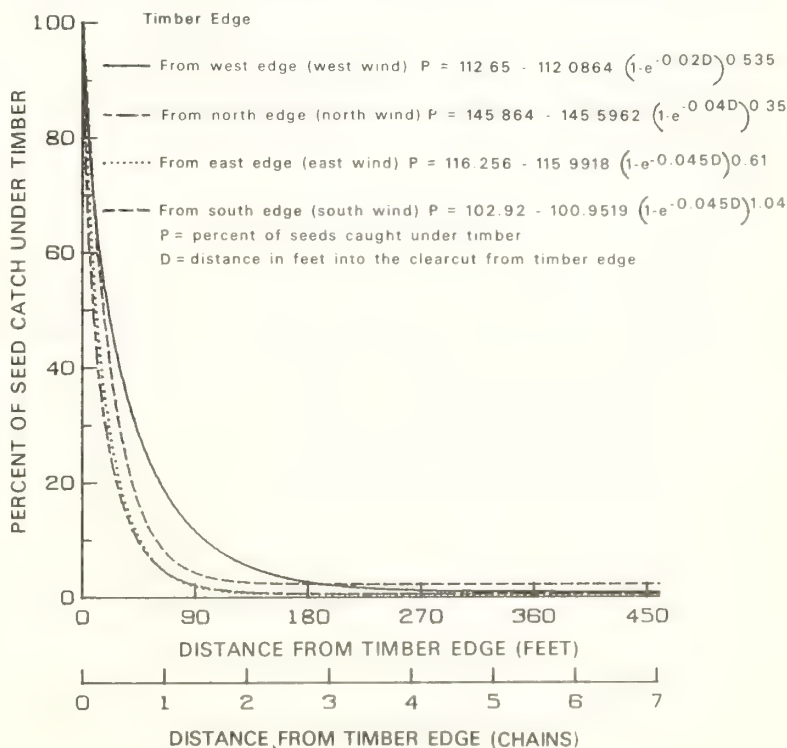
### Dissemination of Seed Into Clearcut Areas

As distance from the timber edge increased, number of seeds disseminated into clearcut areas from surrounding timber edges fell off very rapidly (fig. 7).

At 1 chain, number of sound seeds ranged from 3.2 to 16.2 percent of the number found under the timber. At 3 chains, the percentage dropped to 0.1 to 1.8 percent of the catch under timber.

Wind direction during seedfall appears to have had some effect on distance seed are disseminated into a clearcut from a

Figure 7.--Dissemination of seed into clearcut patches from surrounding timber edges. (For purposes of this graph, the seed catch 1 chain back in the timber was treated as though it occurred at timber edge. This probably has the effect of overestimating seedfall from timber edge to 1 chain out.)



timber edge. More than 16 percent of the seedfall under timber was found 1 chain from the west edge of a clearcut (west wind) as contrasted with only 3.2 percent 1 chain from the east edge (fig. 7).

In 1963, two additional trap lines were installed in different clearcut areas to provide some replication. One of these lines extended into the clearcut from a south timber edge (south wind) and the other from a west edge. Dissemination from the south edge amounted to 13.6 percent and 2.7 percent of the under timber crop at 1- and 3-chain distances, respectively, into the clearcut. Corresponding west edge figures were 8.6 and 1.7 percent, respectively.

Differences between the two sets of south edge and west edge data are not surprising. The first south edge figures--4.4 and 1.3 percent of the crop under timber at 1 and 3 chains from timber edge, respectively--came from a 60-year-old stand that was slightly down slope from the cleared area. The second set (13.6 and 2.7 percent at 1 and 3 chains, respectively) came from 120-year-old timber that was somewhat taller than the 60-year-old trees. Furthermore, the older, taller timber stood on sloping ground that rose slightly above the cleared area. Thus topography and height of timber appear to explain the difference.

Differences between the two west edge lines (14.7 and 2.7 percent of crop under timber at 1 and 3 chains, respectively, into the clearcut versus 8.6 and 1.7 percent) appear to be largely caused by slight differences in topography. However, sampling variations undoubtedly also play a part.

## Discussion and Application

Size and frequency of seed crops pro-

duced by ponderosa and lodgepole pines contrast sharply. At Pringle Falls, lodgepole pine produced nine seed crops with 200,000 or more sound seeds per acre out of 16 years. There were 3 additional years with more than 150,000 sound seeds per acre. If we assume 150,000 sound seeds per acre is enough to produce an adequate crop of seedlings, given favorable germination and survival conditions, lodgepole pine produced 12 adequate seed crops out of 16 years. Similarly ponderosa pine produced five adequate seed crops in 22 years.

Seed production of lodgepole pine in low lying frost pockets deserves further investigation. The frost damage reported by Sorensen and Miles (1974) suggests that seed crops might be smaller and less frequent in frost pockets. However, it takes more than casual observation to establish such a relationship. Lodgepole pine cones are not easily seen unless they are abundant. Mowat<sup>10/</sup> for example, had this to say about the 1953 lodgepole pine cone crop in the vicinity of the seed traps: "Cone crop was first thought to be very light in this area--a few cut-off cones were seen on the ground, but very few on the trees. The catch of seed suggested that this observation may not have been thorough enough, and closer inspection revealed that the crop should rate at least 'light', as there were a fair number of cones on a few trees and a few on many of the best producers. One must look quite closely in this stand, as cones are relatively small and production is mostly at the tops of trees." Estimated seed production based on the catch in traps was

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<sup>10/</sup> From a memorandum with file designation RS - NW, REGENERATION, seed studies, seedfall on Pringle Falls E. F., D40 entitled "Notes for data file on 1953 cone crop," dated 10/2/53 by Edwin L. Mowat. This memorandum is on file at the Silviculture Laboratory, Bend, Oregon.

approximately 160,000 sound seeds per acre that year. If a careful observer like Mowat could so badly underestimate the lodgepole pine seed crop, there is a good possibility that most other foresters could also.

Opportunities to provide seed for natural regeneration of lodgepole pine obviously occur much more frequently than for ponderosa pine. However, with a shelterwood approach where a substantial overwood is reserved, waiting several years for a ponderosa pine seed crop could be acceptable practice. Where a long wait between logging and a seed crop occurs, another site preparation job may be necessary just before or immediately after seedfall but before spring germination begins.

Selection of trees to save as a seed source in a shelterwood type cut should logically follow nature's scheme. The largest, most vigorous, full-crowned dominants are the best genetic base for the next crop; and at the same time, they are the best seed producers. Fowells and Schubert (1956) found that approximately 97 percent of the ponderosa pine seed in the west side Sierra type was produced by dominant trees. Similarly, Bates (1930) found a strong relationship between seed production and vigor and dominance of lodgepole pine. Consequently, if a reasonable shelterwood consisting of the largest, most vigorous trees is retained, the bulk of the stand's seed producing capacity will also be retained in either ponderosa or lodgepole pine stands.

The question, how many seeds are required to produce an acceptable crop of seedlings, is not well answered. Foiles and Curtis (1973) reported in one instance it took 55 seeds to produce one established seedling on scarified soil.

Not all years are favorable for natural regeneration. Cochran (1973) points out, "A series of events is necessary for natural regeneration.... Germination must be favored by warm and moist surface soils, daily surface temperature variation must be moderate, seedlings must survive summer drought, and weather conditions must prevent severe frost-heaving the fall after germination and the next spring." Clearly, some years more nearly meet these conditions than others. Cochran (1973), for example, reports germination of lodgepole pine seed ranged from 0.7 percent in 1972 to 45.5 percent in 1971 on one area. Furthermore, squirrels and other small mammals cut cones and eat seeds. Consequently, a large number of seeds, perhaps as many as 150,000 per acre, are needed to assure an adequate seed supply assuming other conditions are reasonably favorable.

Conditions for germination of seeds and survival of the resulting seedlings can also reasonably be expected to vary from one habitat type to another. Cochran (1973) did not report encouraging results from his studies in the lodgepole pine flats. However, the 1968 and 1971 seed crops produced an abundance of ponderosa pine seedlings<sup>11/</sup> on Pringle Butte in the ponderosa pine/snowbrush community where the soil was well scarified (fig. 2).

Number of seeds dispersed into clear-cut patches falls off rapidly as distance from timber edge increases. Only 2 or 3 percent of the lodgepole pine seed catch under timber falls at a distance of 2 chains from timber. Furthermore, the tremendous range in temperature of pumice soil seedbeds and the tendency for those extremes to be greater in larger clear-cuts (Cochran 1969a, 1969b) makes natural regeneration of large openings

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<sup>11/</sup> Unpublished data on file at the Silviculture Laboratory, Bend, Oregon.



on pumice flats unlikely. Even in favorable habitat types, increasing the distance seed must fly beyond 2 chains substantially reduces prospects for natural regeneration.

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Seed production estimates for central Oregon ponderosa and lodgepole pines are presented for 11- to 22-year periods.

KEYWORDS: Seed production, ponderosa pine, *Pinus ponderosa*, lodgepole pine, *Pinus contorta*.

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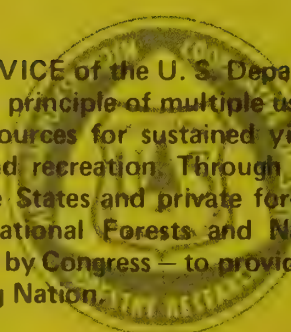
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# PER-ACRE PRICING-- ITS EFFECT ON LOGGING RESIDUE



Thomas E. Hamilton, James O. Howard,  
and Thomas C. Adams

## Abstract

Results are presented of a study designed to test the effectiveness of a combination scale-lump sum timber selling procedure in reducing the volume of logging residue. A comparison was made between National Forest sales by the traditional scale method with a new method incorporating both scale and per-acre pricing of material with less than 80 board feet of volume. Residue volumes were adjusted by covariance analysis to account for the differences in four sale characteristics. Results indicate that, although a difference in average residue volumes occurred between the two sale procedures, the averages were not significantly different at the 5-percent probability level.

KEYWORDS: Slash disposal (-fuel reduction, timber marketing, log value.

Thomas E. Hamilton was project leader of the Marketing Economics Project at the Pacific Northwest Forest and Range Experiment Station at the time the study was initiated; he is now assistant director in charge of planning and application at the Northeastern Forest and Range Experiment Station, Upper Darby, Pennsylvania. James O. Howard and Thomas C. Adams are resource analyst and principal economist, respectively, with the Pacific Northwest Forest and Range Experiment Station.

## Introduction

This paper compares two methods used by the U.S. Forest Service in Oregon and Washington for selling standing timber. One method (scale sales) applies a set price per thousand board feet, by species, to the log scale or the measured amount of timber removed. The other method (*per-acre material* or PAM sales) sells all logs below a given net volume (80 board feet in this study) for a lump sum per acre with larger logs sold on a scale basis. Special peelers (cull peelers) or utility grade logs of any size are also included in the per-acre pricing.

The purpose of the PAM method is to encourage the logging operator to remove more of the low value material that might otherwise be left as logging residue. Removal of this material helps accomplish several objectives of the land manager, including better use of the timber resource, reduced fire hazard, reduced need for slash burning, and improved appearance of the area after logging.

Per-acre pricing allows removal of the low value material without a direct stumpage charge, since it has already been paid for in the fixed cost per acre. In the log scale method the net volume of each piece is measured and paid for at the full stumpage rate for that species. The assumption is that the purchaser will remove more of the total wood volume if he does not have to pay any scaled stumpage charge for the low value pieces. Major arguments for and against log scale and lump sum selling procedures can be found in "Log-scale and lump-sum timber selling on Federal lands in western Oregon" (2).

For example, small diameter logs contain less volume than larger logs, yet take as much or more time to handle in the yarding and loading process. The cost per thousand board feet is therefore greater for smaller logs and the cost: return break-even point is higher. If a stumpage cost is added to the logging cost, the break-even point becomes even greater and less volume would be removed.

The same problem occurs with log defect. A log with some defect that just pays its way without any direct stumpage charge will become uneconomical to the purchaser if it must be scaled and a stumpage charge assessed for the added volume removed.

The effect of lump sum pricing is to make all the stumpage charge a fixed cost to be borne by the sale as a whole, rather than related to the scale of any given log.

The results of this study should be useful in guiding public timber selling agencies toward the most appropriate methods of marketing stumpage. Timber buyers may also find the study useful in helping to formulate a decision on how timber might best be marketed.

## Objective and Procedure

The objective of this study was to measure the effectiveness of the combination log scale-lump sum timber selling procedure in reducing logging residue compared with the traditional log scale method.

The study procedure was to compare the volume of logging residue left on an equal number of clearcut sale areas made under each of the two sale methods. Timber on half the areas was sold by the standard selling procedure of charging a fixed price per thousand board feet for all material removed (scale sales). Timber on the remaining areas was sold for a fixed price per thousand board feet for all material over 80 board feet and a lump sum per-acre price for all material measuring less than 80 board feet (PAM sales).

A total of 38 clearcut areas were measured in the study, 19 for each sale method. Sample size was influenced by the availability of PAM sales and the budget constraints of the study. The 38 areas were randomly selected from the total number of clearcut areas that fulfilled all the conditions described below.

The following limitations were placed on the population of sales from which the sample was drawn to minimize variation due to factors other than sale procedure:

1. All areas were located in western Oregon or southwestern Washington. Sale location could have a strong influence on the volume of residue left after logging because market opportunities can vary widely between timber-sheds. The study area selected was as geographically small as possible while still offering a sufficient population of sales from which to draw the sample.

2. Logging was completed during calendar year 1971. Market conditions in the wood products industry show sharp, short-term fluctuations. To minimize the effect of these changing conditions, sale completion was limited to 1 year.

3. All areas contained at least 500,000 board feet of timber.

4. Clearcut logging was specified on all areas.

5. All areas were part of regular harvest cut sales (not salvage sales).

6. All areas were cable yarded.

7. No area had a YUM (yarding unmerchantable material) requirement.

8. All areas were to be unburned prior to sampling. The original list of sales obtained for each National Forest had no previously burned areas. However, in some cases, burning occurred between the time the sample was



selected and residue measurements were taken. These areas were replaced with alternates selected at the time the original sample was taken.

There are other sale characteristics that could influence the amount of residue left after logging. Data were collected for four characteristics, and residue volume on individual sales was adjusted to account for their influence. The four sale characteristics and their expected influence were:

1. Gross cruise volume of timber per acre was expected to be positively associated with residue volume; that is, as cruise volume increased, residue volume was expected to increase. The logic of this assumption is that a larger volume of timber growing on the area should result in a larger volume of residue material.

2. Average slope of the sale area was expected to be positively related to residue volume. With steeper slopes, logging difficulty would increase and more low value material would be left behind.

3. Stand age should be positively associated with residue volume. This variable should help account for size differences; the older the stand, the larger the trees. Stand age may also be closely associated with the fourth characteristic (percent stand defect) since older stands would be expected to have more defect. Both larger size and additional percent defect should increase volumes of residue.

4. Percent stand defect was expected to be positively associated with residue volume. As more defect is encountered, less of the total volume of material can be economically removed.

## Method of Measuring Residue Volume

The line intersect method of estimating logging residue volume was used in this study (1, 5, 6). Because of problems with uneven distribution of residue and varying sizes and shapes of clearcut tracts, an alternative to the continuous line intersect approach was used. This alternative, tested and recommended for measuring residue on cable logged areas by Howard and Ward (4), uses a systematic grid-point sampling design. Howard and Ward's results indicate that about 40 sampling units are needed to meet a degree of precision of at least 20-25 percent on each clearcut area at the 95-percent confidence level. This number of 200-foot sampling units per clearcut area is about the most an inventory crew can measure in 1 day.

A 40-point grid was laid on each clearcut area. The spacing interval between grid points was the same within each clearcut but varied between clearcuts depending on their size. From each grid point, measurements were made along a 200-foot randomly oriented line. All pieces 3.5 inches or more in diameter and 4 feet or longer were measured. Estimates of the percent soundness of the cross section at the point of intersection with the line transect were recorded to obtain net volumes of residue. These estimates were based on observed defects of each piece, without bucking, at the point of intersection.



## Study Results

Average gross and net chippable residue volumes per acre for each method are:

| <u>Method</u>                         | <u>Measured<br/>average volume</u> | <u>Adjusted<br/>average volume</u> |
|---------------------------------------|------------------------------------|------------------------------------|
| <i>- - - - - Cubic feet - - - - -</i> |                                    |                                    |
| Scale sales:                          |                                    |                                    |
| Gross                                 | 2927.3                             | 2604.7                             |
| Net                                   | 1789.0                             | 1663.0                             |
| PAM sales:                            |                                    |                                    |
| Gross                                 | 1914.4                             | 2237.0                             |
| Net                                   | 1258.5                             | 1384.3                             |

The measured average volumes were statistically adjusted to eliminate the variation between the mean volumes attributed to the differences in the observed stand characteristics, i. e., gross cruise volume, average slope, stand age, and percent stand defect. The adjusted volumes were used for a statistical comparison between the average volumes of the two sale methods. The average values of the sale characteristics by type of sale were:

| <u>Sale<br/>characteristics</u> | <u>Unit of<br/>measure</u> | <u>Scale<br/>sales</u> | <u>PAM<br/>sales</u> |
|---------------------------------|----------------------------|------------------------|----------------------|
| Gross cruise volume             | M fbm/acre                 | 70.0                   | 61.3                 |
| Average slope                   | Percent                    | 34.7                   | 36.5                 |
| Average stand age               | Years                      | 309                    | 211                  |
| Average stand defect            | Percent                    | 34.5                   | 25.2                 |

Gross cruise volume, stand age, and stand defect were all appreciably higher on the scales sales. Only percent slope, which was slightly greater for PAM sales, did not show a large difference between the two types of sales. Because the values for each characteristic are different between sale types, the two groups of sales would be expected to have a different average residue volume regardless of sale method. To eliminate the influence of the unequal values of the independent variables, the average residue volume for

each sale type was statistically adjusted.<sup>1/</sup> The adjusted average gross residue volumes were 2,604.7 cubic feet per acre for scale sales, and 2,237.0 cubic feet per acre for the PAM sales, a difference of 14.1 percent. Corresponding adjusted volumes for net chippable material were 1,663.0 and 1,384.3 cubic feet per acre for scale and PAM sales, respectively, a difference of 16.8 percent.

## Conclusions

Results of this study show only a weak statistical basis for concluding that the PAM method of timber sale yields less residue than the scale method.

Four sale characteristics, taken together, do explain a significant amount of the variation in gross logging residue.<sup>2/</sup> These are cruise volume, slope, stand age, and percent of stand defect. The importance of these factors indicates that the total environment within which the timber sale is made may be the key to why varying amounts of residue are left after timber is harvested. Further study of the physical characteristics of the timber and the timber sale area, together with consideration of economic and institutional factors, such as timber sale policy, surrounding the harvest operation, may provide a means for more accurately forecasting residue conditions on harvested areas.

Moreover, the decision of the land manager to offer scale or PAM sales can also rest on other factors such as efficiency of scaling and sale administration, the need for more accurate cruising and appraisal methods, and consideration of possible changes in operators' bucking practices.

---

<sup>1/</sup> The measured average volume of each sale method was adjusted by covariance analysis. These adjusted averages were then used to test the hypothesis that the average volumes of residue of the two methods were equal. The results of the test indicated that the average volumes were not significantly different at the 5-percent probability level. However, the averages were significantly different at the 10-percent probability level--not strong statistical evidence for concluding a real difference exists between the two methods in generation of residue.

<sup>2/</sup> Multiple regression analysis showed that differences due to the combined effect of four sale characteristics--cruise volume, slope, stand age, and percent stand defect--are statistically significant. The relationship of these factors to residue volume for the combination of both sale methods is estimated by the regression equation:

$$Y = 1161 + 9.835X_1 - 28.42X_2 - 0.1559X_3 + 55.84X_4$$

where

$Y$  = Gross residue volume per acre, in cubic feet

$X_1$  = Gross cruise volume per acre, in thousand board feet

$X_2$  = Slope, in percent

$X_3$  = Stand age, in years

$X_4$  = Percent stand defect

Data were collected for this study in 1972 for timber sale areas logged in 1971. The PAM sale procedure was relatively new in 1971, and as the Forest Service and sale purchasers gain experience with the procedure, residue volumes may change on PAM sale areas. Residue volumes on both PAM and scale sale areas may be affected by economic conditions of industry at the time of harvest. Year-to-year variations in economic conditions may cause year-to-year variations in residue volumes.

The demonstrated importance of the four measured timber sale characteristics and the possible effect of other factors surrounding a timber sale may have important implications regarding the design and selection of timber sale methods. In particular, the findings suggest that a single sale procedure for all timber sales may not offer the best alternative for reduction of residue. Instead, the most appropriate approach may be to vary the procedure according to each sale's particular characteristics.

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## Appendix

Multiple regression analysis for the four variables, cruise volume, slope, stand age, and percent stand defect, had a coefficient of multiple determination,  $R^2$ , of 0.67. This means that 67 percent of the variation can be explained by these factors. Analysis of covariance gave the common regression equation shown in footnote 2, p. 5.

The test of significance gave an  $F$  value of 2.34, for 4 and 28 degrees of freedom. To meet the 5-percent probability level, the  $F$  value would have to be 2.64 or greater. However, the 10-percent probability level requires an  $F$  value of only 2.11. Therefore, the test was significant between the 10- and 5-percent probability levels.

The negative coefficients for stand age and slope at first glance seem inconsistent, yet may be explained by interaction among the four variables. No cause and effect relationship can be inferred from the sign of the coefficients in the regression equation in footnote 2.

Our analysis was based on gross residue volume, because results for net volume had much greater total variation due to the difficulty of judging net volumes accurately in the line transect method. Statistical tests gave much lower levels of significance for the net volume analysis.





Hamilton, Thomas E., James O. Howard, and Thomas C. Adams  
1975. Per-acre pricing--its effect on logging residue.  
USDA For. Serv. Res. Pap. PNW-192, 7 p.  
Pacific Northwest Forest and Range Experiment  
Station, Portland, Oregon.

This paper presents the results of a study designed to test the  
effect on logging residue of two National Forest sale methods. The  
study compared scale sales and sales using a combination of scale  
and per-acre pricing.

KEYWORDS: Slash disposal (-fuel reduction, timber  
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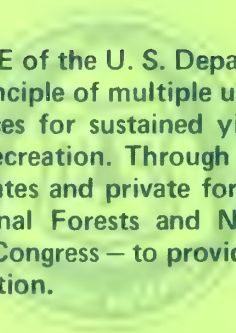
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# Analysis of Running Skyline With DRAG



Ward W. Carson





# Analysis of Running Skyline With Drag

## Reference Abstract

Carson, Ward W.

1975. Analysis of running skyline with drag. USDA  
For. Serv. Res. Pap. PNW-193, 8 p., illus.

Discusses the mathematical description of a running skyline system which is used to drag logs in a timber harvesting operation. The description is the foundation for a method of computer prediction of the load-carrying capability of these systems. This information is useful to logging engineers in developing harvesting plans for running skyline logging operations.

Keywords: Skidding, cable skidding methods,  
computers (electronic).

## RESEARCH SUMMARY Research Paper PNW-193 1975

For several years, logging engineers involved in developing harvesting plans for the running skyline have been using computational methods to determine the load-carrying capability of these systems. The methods available for these computations have been either hand procedures or digital computer solutions for the specific configurations of a log load suspended free of the ground or in frictionless contact with level ground. The more typical operation, however, drags one end of the log load along the ground. The dragging configuration, considered in this paper, can influence the load-carrying capability of a running skyline significantly.

The dragging log problem was posed mathematically as a requirement to determine the deflection of a loaded skyline when the anchoring geometry,

the log-to-ground geometry, the coefficient of friction between ground and log, the weight of cables, and the operating tension of the system are considered known. The description and method used to analyze the dragging log configuration did not account for the exact weight associated with catenary shaped cables but rather approximated their weights with a straight-line assumption. This allowed an algorithm that converges rapidly and provides a high degree of accuracy.

The solution procedure reported in this paper was used in a computer program reported in another publication, "Programs for Skyline Planning," USDA Forest Service General Technical Report PNW-31. Those programs are being used by many logging engineers in the USDA Forest Service, other Government agencies, universities, and the private sector of the timber industry.

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## 1.0 Introduction

For several years, timber harvest planners have been designing skyline logging operations for the running skyline. One major step in this planning process is the determination of the load-carrying capability of the skyline while anchored in specific geometry and operating over specific terrain. Several methods have been available to compute these capabilities (Carson and Studier 1973, Carson et al. 1971, Lysons and Mann 1967, Mann 1969, Suddarth 1970); however, each method is based on the assumption that the load consists exclusively of the vertical component as would result from either a log load suspended free of the ground or in frictionless contact with level ground. Such is not generally the case in actual operation. Although the loads may be held free of the ground over streams or other sensitive terrain features, it is more typical to drag one end of the log load on the ground. In this configuration, a portion of the

load is borne by the ground which increases the size of load that can be carried but adds another force due to the drag of the load on the ground. Planners of a running skyline harvest layout for this type of operation need to determine the influence of drag upon the capability of the system.

This paper presents a mathematical method for determination of loading conditions when the logs are being dragged along the ground by a running skyline. The method is an extension of that discussed by Carson and Mann (1971). Carson (1975) reported on a programed solution based on this method.

## 2.0 Mathematical Problem

A large part of the mathematical description of the running skyline problem presented by Carson and Mann (1971) applies to the problem treated in this paper. Their statement of the problem was based on a schematic representation of the skyline as shown in figure 1. This figure identifies the

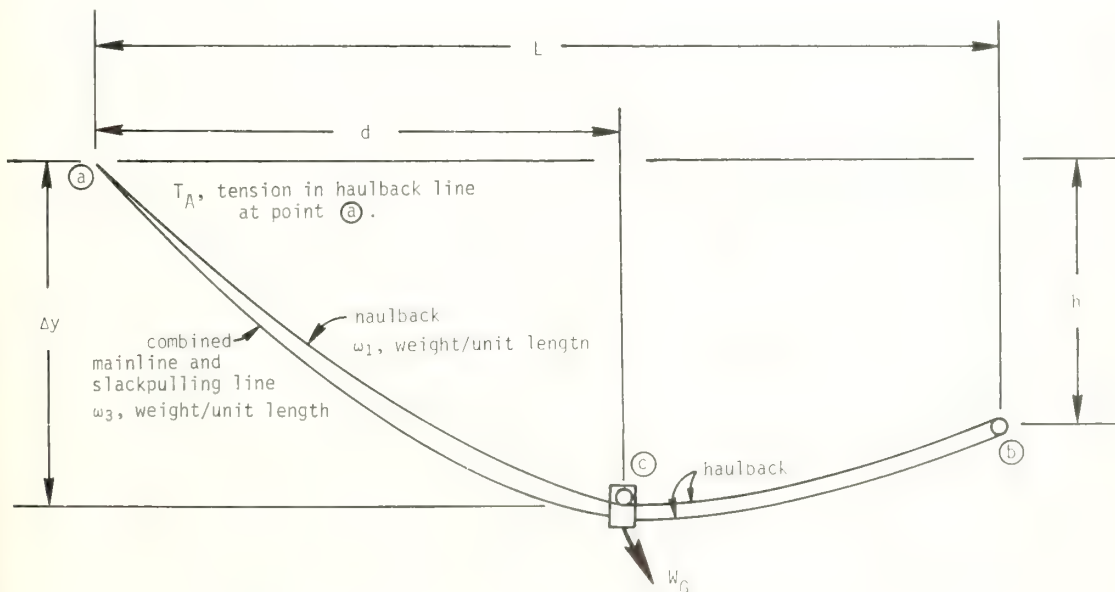


Figure 1.--Schematic of the running skyline.

important geometric variables of span  $L$ , vertical anchor point separation,  $h$ , and the carriage location coordinates,  $d$  and  $\Delta y$ . As in Carson and Mann's paper, the weight per foot of the haulback line,  $\omega_1$ , and the weight per foot of the combined main line and slack-pulling (or grapple opening) line,  $\omega_3$ , are assumed to be known. Again, the haulback operating tension,  $T_A$ , is taken as a known quantity.

The extension presented in this paper results from the allowance for a more general loading situation. The vertically oriented gross payload in the Carson and Mann (1971) paper is replaced with a vertical carriage load,  $W_C$ , plus a log load with drag which combines to give a resultant gross load,  $W_G$ , that is not vertical in general.

The analysis presented here then addresses itself to determination of the displacement,  $\Delta y$ , necessary to support the load represented by  $W_G$  while the skyline system is maintaining a haulback tension,  $T_A$ . A curve connecting a series of these displacements at several locations in the span (i.e., several  $d$ 's) is referred to as the load path.

## 2.1 PROBLEM FORMULATION

Carson and Mann (1971) presented an analytical approach to the running skyline problem that averted the difficulties associated with the catenary description of cable problems. This approach, called the force balance formulation, will be used here also for the benefit of a simplified mathematical description. The efficiency of the method and the accuracy were documented by Carson and Mann.

## 2.2 FORCE BALANCE FORMULATION

The relationship between cable forces and geometry can be derived by consideration of the equilibrium of

components of the running skyline system. The equations are written from force and moment balances for all line segments and for the skyline carriage (see fig. 2). For example, line segment 1 can be described by the vertical force balance on the line segment,

$$V_1^a = R_1 + V_1^c;$$

the horizontal force balance on the line segment,

$$H_1 = \text{constant};$$

and the moment balance about the carriage,

$$V_1^a = R_1 \frac{e_1}{d} + H_1 \frac{\Delta y}{d}.$$

In these expressions,  $R_1$  represents the weight of the cable segment concentrated at a horizontal distance,  $e_1$ , from the carriage; and the other forces and distances are described in figure 2.

The other line segments can be described by similar expressions so that the vertical forces at the carriage can be stated as

$$V_1^c = R_1 \left( \frac{e_1}{d} - 1 \right) + H_1 \frac{\Delta y}{d} \quad (2.2.1)$$

$$V_2^c = R_2 \left( \frac{e_2}{L-d} - 1 \right) + H_2 \frac{\Delta y - h}{L-d} \quad (2.2.2)$$

$$\text{and } V_3^c = R_3 \left( \frac{e_3}{d} - 1 \right) + H_3 \frac{\Delta y}{d} \quad (2.2.3)$$

These forces can be related to the forces on the carriage through the force balance equations

$$V_1^c + 2V_2^c + V_3^c = W_V + W_C \quad (2.2.4)$$

$$\text{and } H_1 + H_3 - 2H_2 = W_H \quad (2.2.5)$$

These equations include representation for a load vector that may include both vertical,  $W_V$ , and horizontal,  $W_H$ , components as well as the vertical component of the carriage weight,  $W_C$ .



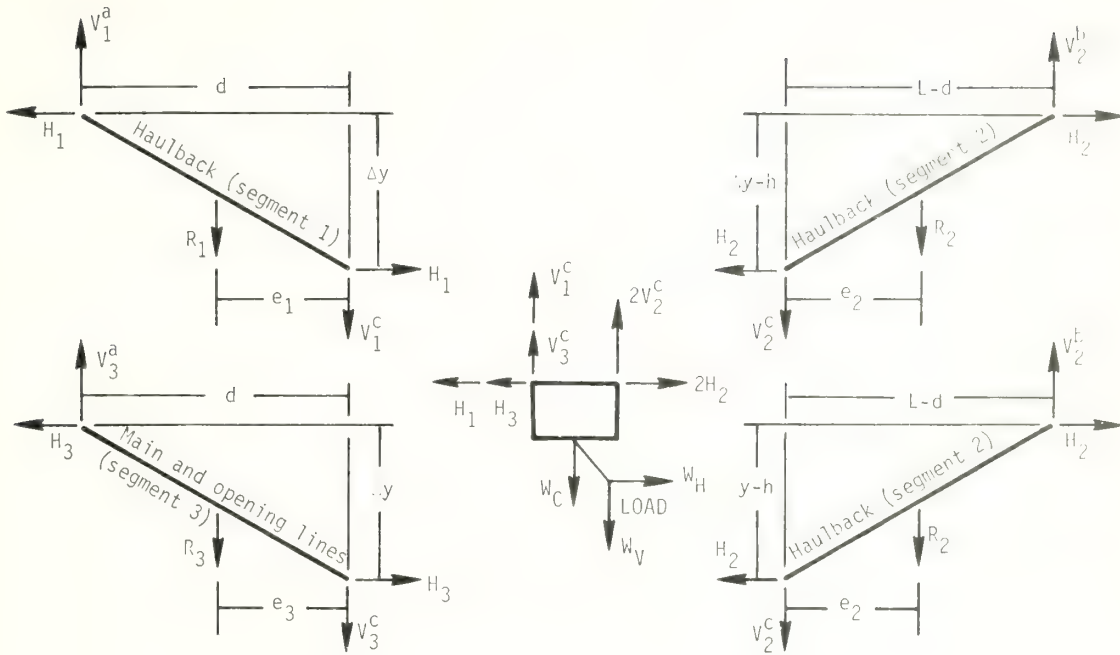


Figure 2.--Force balance formulation.

In a later section, the load vectors,  $W_V$  and  $W_H$ , will be expressed in terms of conditions experienced by a dragging log load. To implement a solution procedure for determination of the influence of these vectors upon the geometry and tension of the cable configuration, the equations of this section are combined to yield

$$\begin{aligned}
 W_V + W_C - W_H \frac{\Delta y}{d} &= 2H_2 \left( \frac{\Delta y - h}{L - d} + \frac{\Delta y}{d} \right) \\
 &+ R_1 \left( \frac{e_1}{d} - 1 \right) + 2R_2 \left( \frac{e_2}{L - d} - 1 \right) \\
 &+ R_3 \left( \frac{e_3}{d} - 1 \right) \quad (2.2.6)
 \end{aligned}$$

This equation forms a clear statement of the relationship between the loading at the carriage and the geometry, cable weights, and haulback cable tensions. It will be used in "Solution Procedure" (section 4.0).

### 2.3 FORCE BALANCE FORMULATION WITH STRAIGHT-LINE APPROXIMATIONS

The equations of the last section require the weights,  $R_i$ , and moment arms,  $e_i$ , of each segment. The catenary lengths and shapes of these segments, however, are not known until solutions for tensions in each line have been established. Therefore, an exact solution would require iterations involving assumed tensions which provide catenary geometry, line weights, and moment arms, followed by computation of tensions to be compared with the values originally assumed (Carson and Mann 1971). This procedure can be simplified by approximating the catenary geometry of cable segments by straight-line segments between anchor points. The line segments are envisioned as straight, rigid members with the uniform weight distribution of the cables and pinned at a, b, and c (fig. 1). This

assumption allows the line segments weights and moment arms to be expressed as

$$R_1 = \omega_1 (d^2 + \Delta y^2)^{1/2}$$

$$e_1 = d/2$$

$$R_2 = \omega_1 ((L-d)^2 + (\Delta y-h)^2)^{1/2}$$

$$e_2 = (L-d)/2$$

$$R_3 = \omega_3 (d^2 + \Delta y^2)^{1/2}$$

and

$$e_3 = d/2.$$

This assumption is made in the present analysis. The error introduced in the results is slight. Magnitudes of the error were discussed by Carson and Mann (1971).

### 3.0 Forces Due to Log Drag

An important part of this analysis is the identification of the forces associated with the dragging log load. The algorithm discussed in the previous section presumed that the horizontal and vertical components of this load could be provided as a function of the information about the log and how it is dragged over the terrain. Expressions for these forces are derived in this section.

Consider the log skidding geometry and force vectors as displayed in figure 3. This figure identifies the horizontal and vertical forces so that they can be expressed as

$$W_V = T \cos \alpha = W - N \cos \theta + N \sin \theta \quad (3.0.1)$$

and

$$W_H = T \sin \alpha = N \sin \theta + N \cos \theta \quad (3.0.2)$$

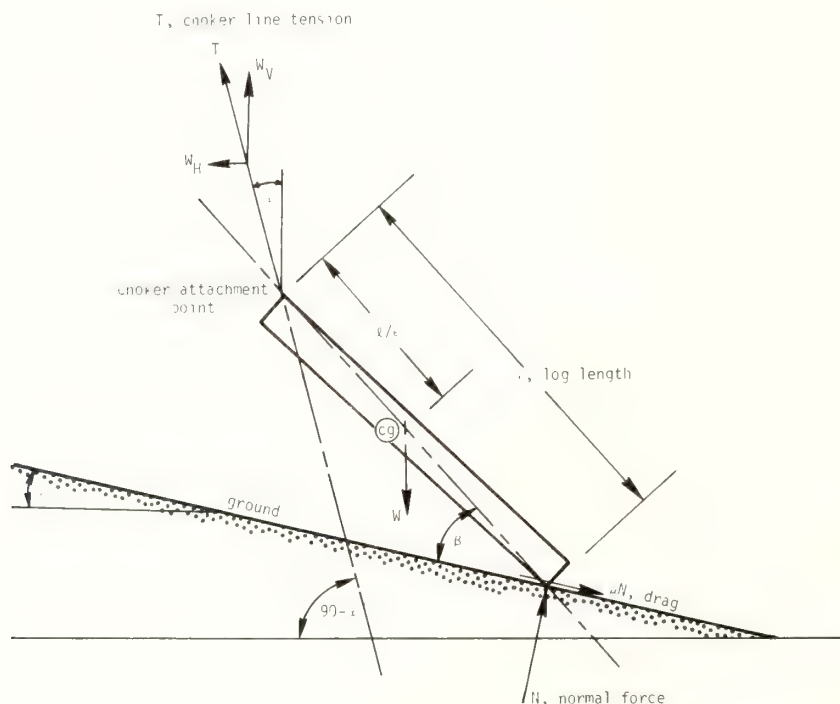


Figure 3.--Log skidding geometry.

where

$T$  = the tension in the choker line,

$\alpha$  = the angle of the choker line with respect to the vertical,

$\theta$  = the local slope of the ground,

$N$  = the normal force,

and

$\mu$  = the coefficient of friction between the log and the ground.

The normal force,  $N$ , is unknown but can be established in terms of the log weight,  $W$ , the angle the log makes with the ground,  $\beta$ , and the location of the log center of gravity with respect to the choker attachment point. The expression relating these variables is

$$N = W / \left[ \epsilon \left( \cos\theta - \mu \sin\theta + \sin\theta \tan(\theta + \beta) + \mu \cos\theta \tan(\theta + \beta) \right) \right]$$

This equation shows that the magnitude of the forces involved in the dragging log can be expressed independently of log length and choker length if the angles  $\theta$  and  $\beta$  are available. By introducing the equation for the normal force,  $N$ , into the expressions for  $W_V$  and  $W_H$ , one obtains

$$W_V = W \left( 1 - \frac{\cos\theta - \sin\theta \tan\beta}{\epsilon(1 + \mu \tan\beta)} (\cos\theta - \mu \sin\theta) \right) \quad (3.0.3)$$

$$W_H = W \left( \frac{\cos\theta - \sin\theta \tan\beta}{\epsilon(1 + \mu \tan\beta)} \right) (\sin\theta + \mu \cos\theta) \quad (3.0.4)$$

If the cable between the log load and the carriage is assumed to be weightless, these equations satisfy the requirement for establishing  $W_V$  and  $W_H$  in terms of the information about the log only.

## 4.0 Solution Procedure

Recall that the goal of this analysis was to determine the displacement,  $\Delta y$ , required to support a log and carriage load represented by  $W_V$ ,  $W_H$ ,

and  $W_C$ . This will depend, of course, upon the tension,  $T_A$ , maintained in the haulback line. This dependence can be expressed by rearranging equation (2.2.6) into the form

$$\Delta y = \frac{W_V + W_C + 2H_2 h / (L - d) + 1/2 (R_1 + 2R_2 + R_3)}{W_H / d + 2H_2 / (L - d) + 2H_2 / d} \quad (4.0.1)$$

where

$H_2$  is a function of  $T_A$  through the catenary relationship

$$(T_A - \omega_1 \Delta y) = \left( (V_2^C)^2 + (H_2)^2 \right)^{1/2} \quad (4.0.2)$$

Unfortunately, the displacement,  $\Delta y$ , remains implicit in all these expressions and cannot be solved for directly. An iterative type solution is required.

The method chosen to solve for  $\Delta y$  is displayed in the flow chart of figure 4. It is not a standard technique; however, for this problem it provides rapid and stable convergence.

## 5.0 Numerical Example

To demonstrate the procedure used to determine displacements at given stations, a numerical computation is presented here. Consider a running skyline with an equipment specification of

$\omega_1$ , haulback line weight per foot = 1.04 pounds per foot

$\omega_3$ , combined weight of main and slack-pulling line = 1.44 pounds per foot

$T_A$ , haulback line working tension at headspar = 19,600 pounds

$W_C$ , carriage weight = 1,200 pounds

with the anchoring geometry of

$L$ , span between headspar and tailhold = 1,500 feet

$h$ , anchor point vertical separation = 600 feet.

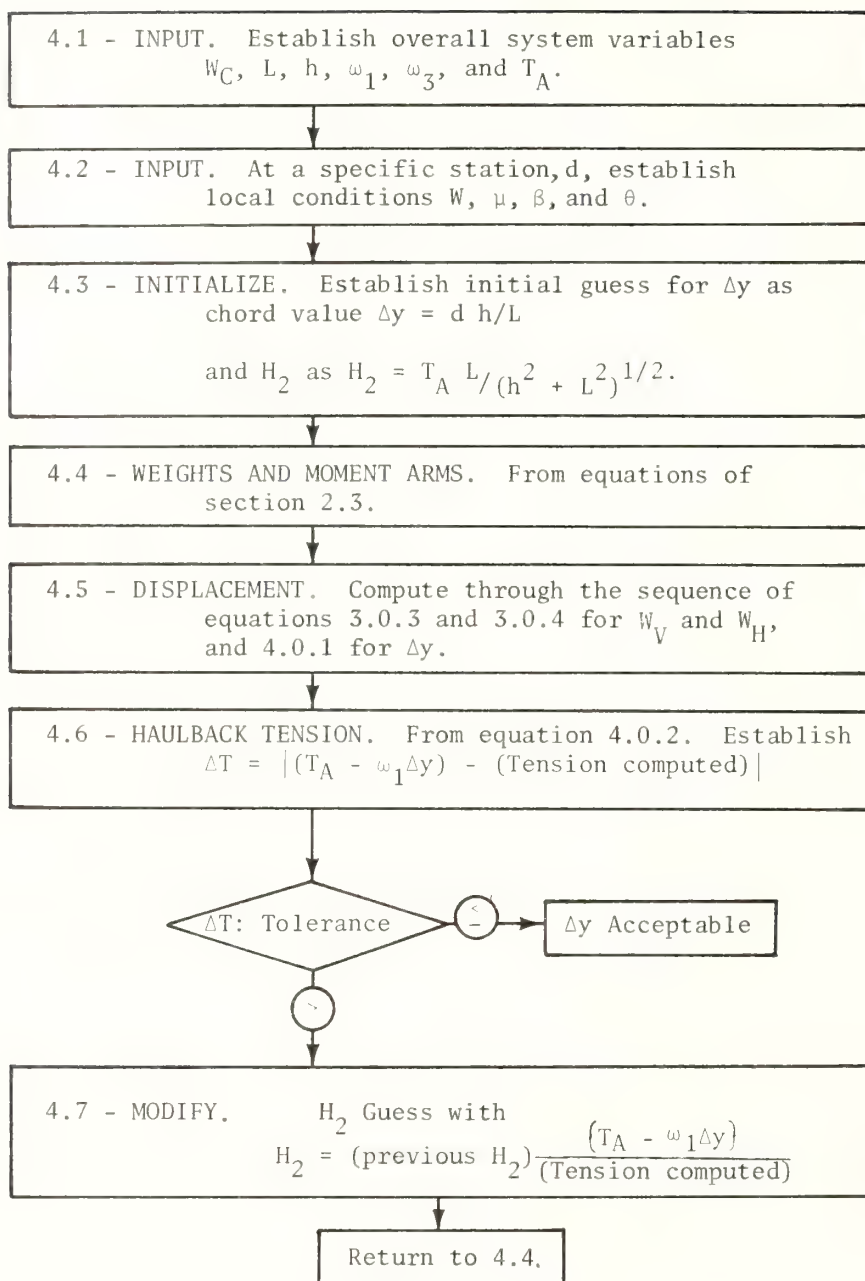


Figure 4.--Flow chart of solution procedure.

In this example, the displacement at the station  $d = 600$  is determined, where the load conditions are given to be

W, log load, one end of which is supported by the ground  
= 10,000 pounds

$\mu$ , assumed coefficient of friction between the load and ground  
= 0.6

$\beta$ , the angle of the load with respect to the ground  
= 5 degrees

and  $\theta$ , the local ground slope  
= 23 degrees (42.45 percent).

With these conditions, the initial guess for displacement and horizontal tension are, respectively,

$\Delta y = 240$  feet

and  $H_2 = 18,198.14$  pounds.

These values lead to initial values for the computed displacement and tension, respectively,

$\Delta y = 319.21$  feet

haulback tension computed  
= 19,551.38 pounds.

The tension discrepancy of  $\Delta T = 48.62$  requires another iteration which yields

$\Delta y = 319.15$  feet

and haulback tension computed  
= 19,595.48 pounds.

After four trials, the guess for  $\Delta y$  is 319.13 which yields a computed haulback tension within 0.01 pound of the required value of 19,600 pounds. The method has been used extensively in a program reported by Carson (1975) and has converged rapidly in all cases attempted.

## 6.0 Conclusions

This paper has presented a mathematical procedure which successfully

models the forces and displacements that exist in a running skyline configuration with a dragging log load. The procedure has been programed for desk-top computer execution by Carson (1975). The description discussed here and used in Carson (1975) should provide the logging engineer with more realistic estimates of the conditions existing in a running skyline system.

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1975. Analysis of running skyline with drag. USDA For. Serv. Res. Pap. PNW-193, 8 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Discusses the mathematical description of a running skyline system which is used to drag logs in a timber harvesting operation. The description is the foundation for a method of computer prediction of the load-carrying capability of these systems. This information is useful to logging engineers in developing harvesting plans for running skyline logging operations.

Keywords: Skidding, cable skidding methods, computers (electronic).

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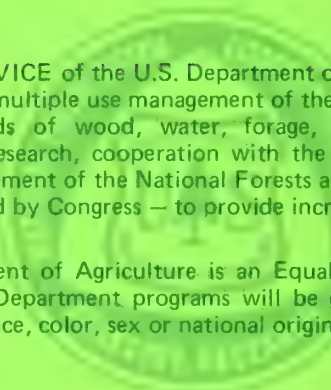
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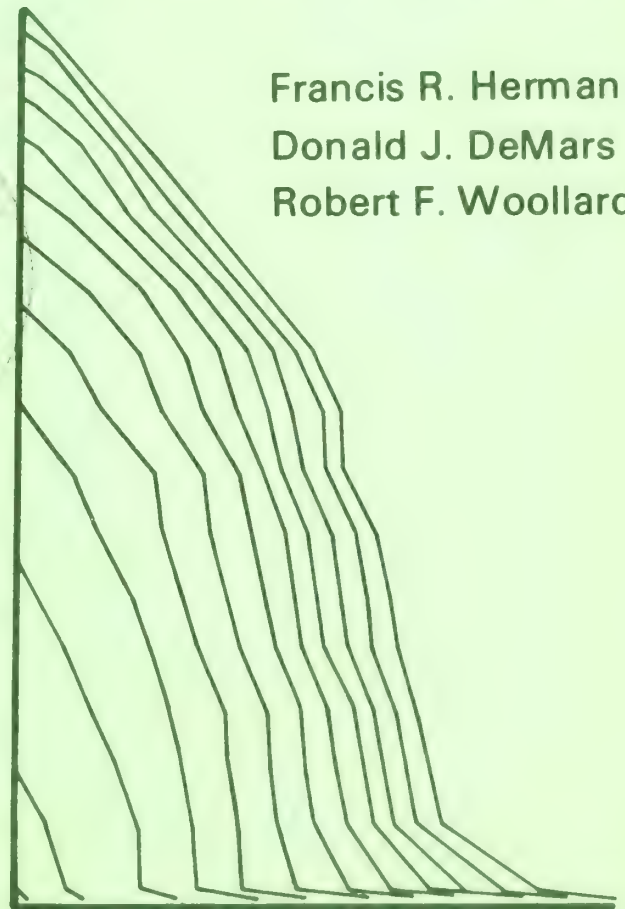


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# Field and Computer Techniques for Stem Analysis of Coniferous Forest Trees

Francis R. Herman  
Donald J. DeMars  
Robert F. Woollard





# FIELD AND COMPUTER TECHNIQUES FOR STEM ANALYSIS OF CONIFEROUS FOREST TREES

## Reference Abstract

Herman, Francis R., Donald J. DeMars, and Robert F. Woollard

1975. Field and computer techniques for stem analysis of coniferous forest trees. USDA For. Serv. Res. Pap. PNW-194, 51 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Field and computer techniques for stem analysis adaptable to both young- and old-growth conifers are presented. Field instructions include a step-by-step explanation of tree cutting, sectioning, ring count, and measurement techniques. A computer program adapted to field techniques re proportions a tree's radial measurement data, calculates height-age-site index information, punches the re proportioned and height-age-site index information on cards, and plots height-age and stem profile graphs. These stem analysis techniques are adaptable to trees of any size up to 800 years old and to either American or metric measures. These instructions enhance the usefulness of the stem analysis research method in obtaining growth information for forest managers.

KEYWORDS: Stem analysis, age determination, ring measurement, data recording methods, old-growth conifers.

## RESEARCH SUMMARY

Research Paper PNW-194  
1975

Stem analysis studies within the upper-slope mixed-conifer forests of the Cascade Range in Oregon and Washington were begun in 1965. Objective of these studies was to develop site quality and comparative growth information among the several coniferous species growing in the true fir-hemlock forests. Work was done within the natural range of noble fir between Stevens Pass in Washington and McKenzie Pass in Oregon. Stem analysis was selected as a technique for developing productivity information because it permitted use of overmature trees to obtain information about growth of both young and old trees.

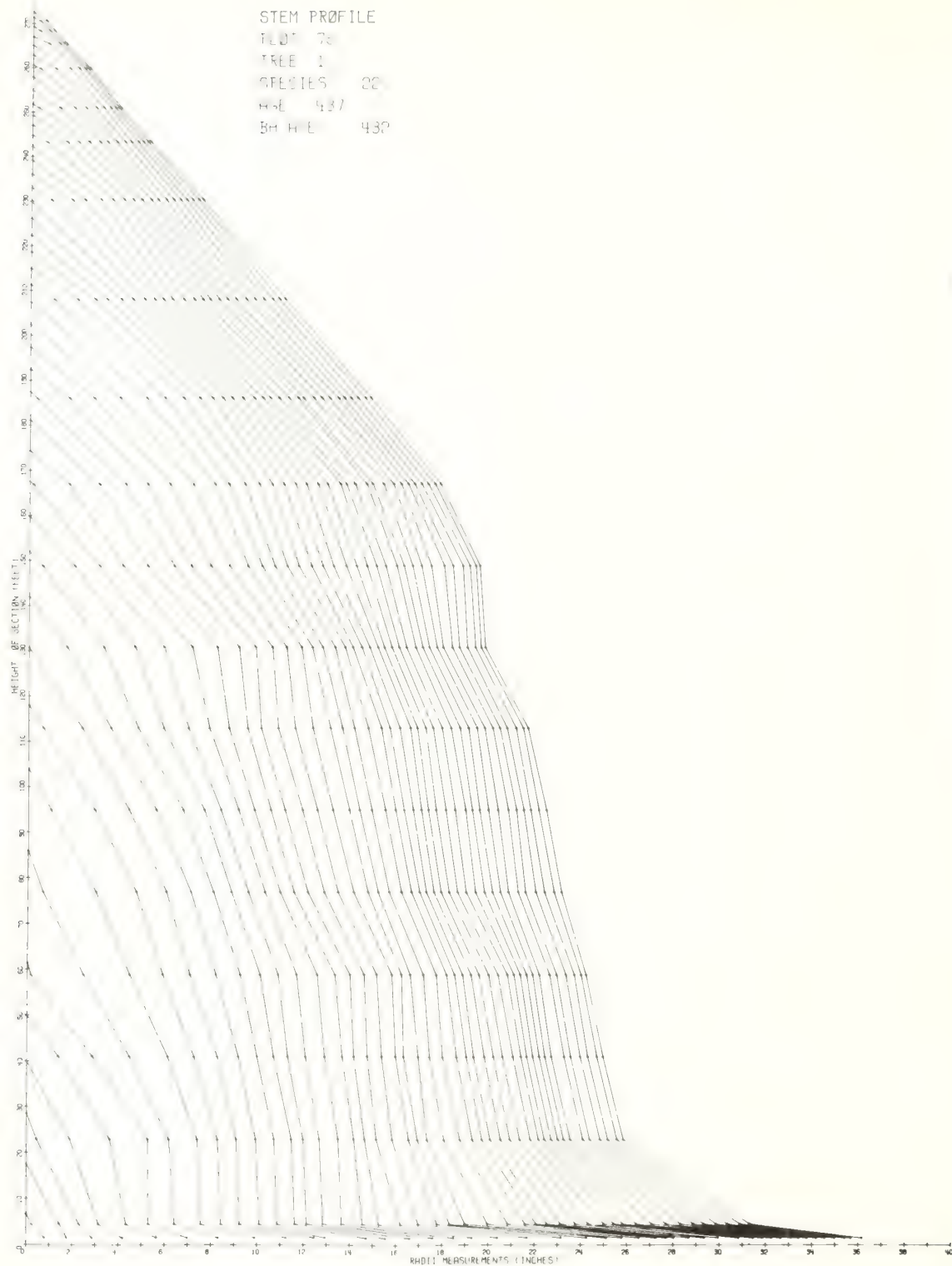
During the course of the studies, efficient methods of data collection and use were devised and applied. From that experience, detailed instructions of stem analysis field methods, including tree felling, sectioning, and measurement of sequential radial growth (SRG), are presented. Three different methods of collecting multiple-ring SRG data are

explained. One method is used as an example to give the reader a complete set of instructions for field collection of data compatible for automatic data processing (ADP). Modification of both data collection and computer programing would be necessary for the other two methods.

Many old and new stem analysis techniques were applied in appropriate succession to develop efficient operations. The goal of these stem analysis techniques is to code and record data compatible for ADP. Output for that ADP consists of re proportioned SRG measurements, stem analysis graph (stem profile chart), and height-age graphs and listings for individual trees. Any or all of the output items may be selected on a single run.

Both field and computer techniques are adaptable to either the American or metric system of measurement--only minor change in programing is necessary for conversion.





*Computer-produced stem profile chart for noble fir  
 with a breast-height age of 432 years.*

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## Introduction

To develop site quality and other growth information essential for proper management of the upper-slope true fir-hemlock forests of the Cascade Range in Oregon and Washington, the U.S. Forest Service and Oregon State University began stem analysis studies in 1965. This work was aimed especially at collection of growth data from old-growth noble fir<sup>1/</sup> for estimation of site index (DeMars et al. 1970, Herman and DeMars 1970). Noble fir stem analysis growth data also were used for comparison of methods of site index estimation (Curtis et al. 1974a); and associated Douglas-fir data were used in development of site index information, specifically for upper-slope Douglas-fir in the Cascade Range (Curtis et al. 1974b).

Species composition within the upper-slope mixed-conifer forests of the Cascade Range is complex. Radiolongitudinal data produced from these stem analysis studies are providing the first information about measured growth relationships among surviving old-growth dominant and codominant individual trees within and between defined habitats. With such a wide representation of different species--as many as 9 or 10 on each acre--considerable latitude is available for selection of a particular combination for managed stands. Comparative growth information has proved valuable in other mixed forest types (Deitschman and Green 1965, Green and Alley 1967, Carmean and Vasilevsky 1971) and will prove equally valuable in the Pacific Northwest.

Besides providing comparative growth information specifically for mixed conifers in the Cascade Range of Oregon and Washington, field and computer techniques

presented in this paper are applicable to stem analysis of both young- and old-growth conifers regardless of where they grow. Furthermore, such techniques are adaptable to either the American or metric system of measurement--only minor change in programing would be necessary for conversion.

Natural forest stands containing noble fir are found in the Pacific Northwest Cascade Range roughly between Stevens Pass in northern Washington and McKenzie Pass in central Oregon (fig. 1). The area south of McKenzie Pass in the Willamette National Forest was excluded from the study to avoid confusing growth variation caused by hybridization with Shasta red fir. However, a few Shasta red fir and associated tree species were sectioned for comparative studies in southwestern Oregon. Table 2, appendix I, presents a list of the important upper-slope coniferous tree species with their assigned numerical computer codes.

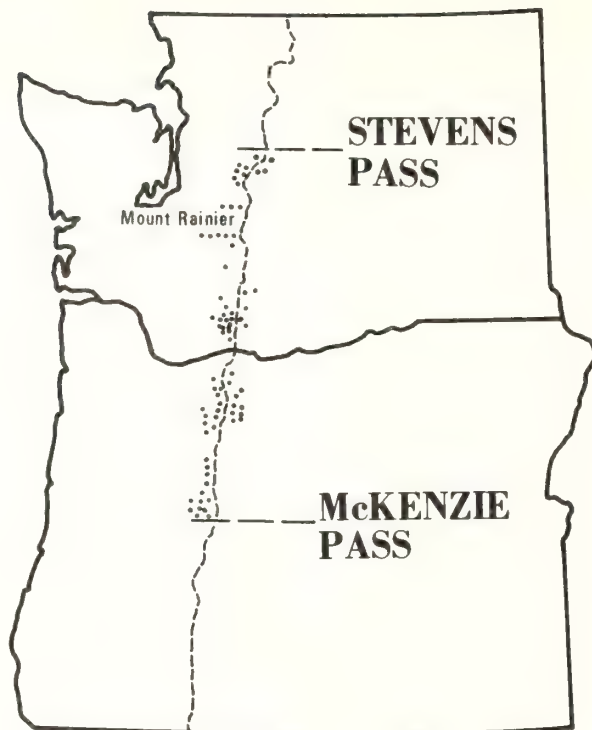
Because few upper-slope forest stands of 150 years of age and younger were found in the Cascades, older trees were selected for study. Our stem analysis technique permitted us to use overmature trees to obtain information on growth of both young and old trees. Furthermore, stem analysis as a technique was adapted to this growth-evaluation research because no uniform and random range of age classes existed throughout the noble fir range. Except for infrequent, scattered young-growth stands arising from some catastrophic event such as fire or windstorm, most stands were 200 to 400 years old.

The stem analysis approach has the inherent disadvantage of dependence among successive measurements on the same sample tree and presupposes that selected trees were always dominant

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<sup>1/</sup> See table 2, appendix I, page 22, for scientific names of trees.

Figure 1.--Stem analysis study locations within the natural range of noble fir in Oregon and Washington.



throughout their lives (Schlich 1895, Dahms 1963). This disadvantage may or may not be important. During our quest for upper-slope noble fir and Douglas-fir site index information, occasional checks of heights of two to four dominant noble fir trees at selected ages at given locations showed no significant changes in dominance.

There are several advantages to the use of the stem analysis method. These have been discussed at length by several workers over many years. Curtis (1964) refers to much of that literature and points favorably toward the use of the method.

The disadvantage of dependence among successive measurements on the same tree can be minor compared with the disadvantages associated with the empirical method of attempting to span a site quality interval for a given species by

selecting for measurement a great many representative temporary forest plots. Stem analysis provides a solution to the problem of unbalanced site selection over a wide range of ages because a uniform number of height observations always is available for any given age for all selected sites.

Even with such widespread species as Douglas-fir (McArdle et al. 1961) and western hemlock (Meyer 1937, Barnes 1962), research workers using stand data were not able to select equal numbers of stands for all ages over an equal number of potential growing sites. Beck and Trousdell (1973) discussed and demonstrated the effect of that problem of disproportional sampling of site and age.

Procedures for stem analysis of trees have been both briefly and comprehensively described in many basic and advanced forestry measurement textbooks and



bulletins at least as early as 1895 (Schlich). A complete description of stem analysis methods and uses in early American forestry literature was presented by Mlodziansky (1898). Detailed field and office procedures included use of such data to determine past and current volumes of individual trees. Many other references to early American forestry stem analysis methods and uses are given by Spurr (1952) and Turnbull.<sup>2/</sup> Later references to the technique and one of the most complete contemporary descriptions of procedures are contained in a mensuration text by Husch (1963).

Our paper describes for the first time detailed and complete procedures, including collection of field data and use of that data, for stem profiles and height-age curves produced by Automatic Data Processing (ADP).

Objectives of this paper are:

1. To describe the field and laboratory procedures actually used in stem analyses.
2. To recommend field and laboratory procedures applicable to similar studies and forestry education exercises.
3. To present a stem analysis computer program with instructions for its use.

Techniques of field, laboratory, and computer operations presented in this paper are purposely detailed to furnish step-by-step instructions for those who wish to use our stem analysis procedures to develop site index information and secure stem profile data for growth comparisons and volume determinations.

<sup>2/</sup> Kenneth J. Turnbull. Stem analysis techniques and applications and some studies of second-growth Douglas-fir in western Washington. Unpublished M. F. thesis, University of Washington, Seattle, 1958.

## Stem Analysis Field Methods

Hundreds of true fir-hemlock stands within the natural range of noble fir were visited. From these stands, study locations were selected. Habitat type and understory vegetation differentials<sup>3/4/</sup> at varying elevations and latitudes were bases for selection. Frequently, site continuums were selected--as from ridgetop to valley bottom.

### TREE SELECTION AND PREFELLING MARKING AND MEASUREMENTS

After each location was determined, the tallest dominant or codominant tree of each species (table 2, appendix I) present within approximately one-fourth acre was selected for stem analysis. Trees with obvious defects such as thin crowns, stag, forked, or broken tops, and bent and crooked stems were avoided, as were severely leaning or unbalanced trees. Rot indicators such as conks, catfaces, frost cracks, and abnormal stem swelling caused trees to be rejected. Any tree suspected of decay was "bored" at stump height with the rounded tip of the chain saw. Expelled wood fragments were monitored for rot. Trees with "brooms" in the crown, whether caused by dwarf mistletoe or some other disease, were taken if nothing else was available.

After trees were selected and before they were felled, they were circumscribed at stump and breast heights with spray

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<sup>3/</sup> Jerry F. Franklin. Study plan for development of a habitat type classification of the true fir-hemlock forests of the southern Washington Cascades. 51 p. Unpublished report, Forestry Sciences Laboratory, Corvallis, Oregon, 1962.

<sup>4/</sup> Jerry Forest Franklin. Vegetation and soils in the subalpine forests of the southern Washington Cascade Range. Ph. D. thesis, Washington State University, Pullman, 132 p. 1966.

paint, in planes at right angles to the vertical axes of stems. Stump and breast height diameters were measured with a diameter tape. Where information about stem cross-section eccentricity in relation to cardinal direction was desired, special stump and breast height stem marks were made before trees were felled. North and south (or east and west) cardinal direction stem exposures were marked with vertical spray paint lines (fig. 2). Analyses of cross-section

## TREE FELLING

Where possible, felling was done along contour--not over drainages or rock outcrops--to avoid excessive breakage. Felling into adjacent trees was avoided as much as possible to prevent hangups, severe breakage, and loss of candidate treetop. Stands with hemlocks were especially difficult to work within because the long crowns easily became entangled.

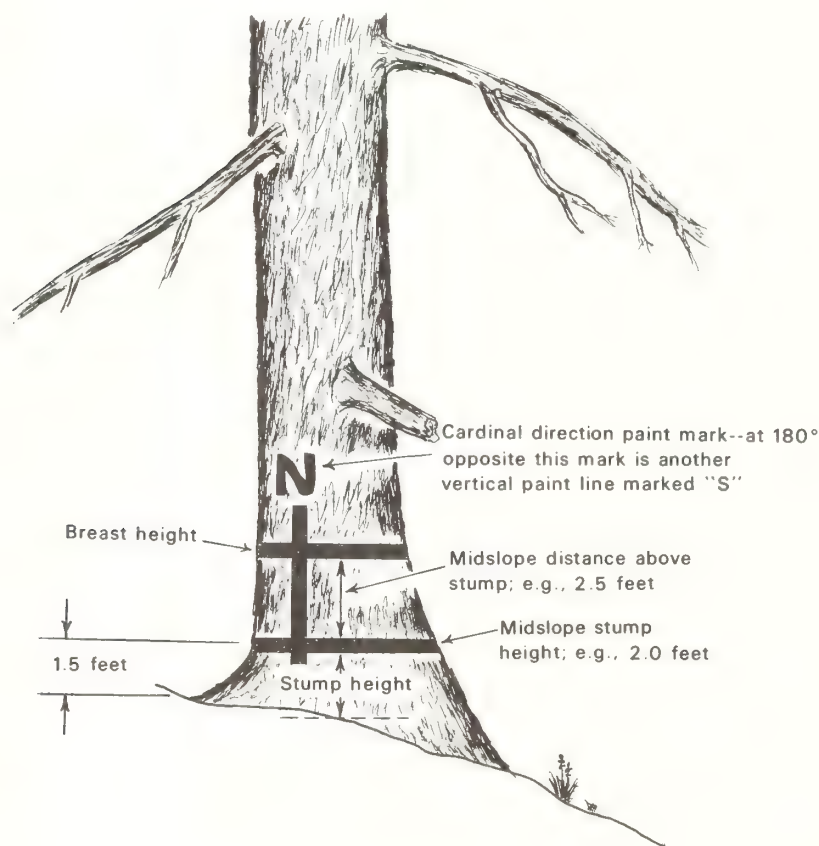


Figure 2.--Diagram showing painted stump ring, breast high ring, and cardinal direction, or exposure reference marks.

eccentricity information are made separately from the same ring count and ring interval measurement data collected for height-diameter and height-age growth evaluations.

The stump was cut either 2 inches above or 2 inches below the stump ring mark, with care taken not to undercut across the stump mark. If the cut was below stump mark, the undercut left a flat surface on

base of upper stem section. If cut was above stump mark, the undercut left a flat surface on stump. The stump section was prepared for measurement by cutting through the painted ring. When slightly leaning or unbalanced trees necessarily were selected, special care in stump preparation was taken to avoid pulling long splinters of wood from the stem or stump. Back cut was always maintained parallel to undercut. Side cuts were made to prevent longitudinal "barber chair" splitting of the stem.

## **TREE STEM REASSEMBLY AND MEASUREMENT**

The tree was limbed from stump to top, including all broken stem parts. Before length measurements were taken, all broken stem pieces were matched to provide accurate information on stem length. Broken bark and wood patterns, wood grain patterns, and knot arrangements provided "keys" to accurate "reassembly." Broken pieces quite often were impossible to physically join together because of weight and displacement distances. Pressurized spray paint cans with a fine nozzle provided a good method of marking matching points on broken stems.

## **TREE SECTIONING**

All points on tree stem where sectioning cuts were to be made were marked with paint. Cuts were made at short log length intervals so they could be salvaged. Although actual measurements varied, the most satisfactory sectioning sequence for both salvage and good stem profile data was: stump height, 4.5 feet (1.37 meters) above ground (breast height); 9 feet (2.74 meters) above b.h.; then 18 feet (5.47 meters); 36 feet (10.94 meters); etc., by 18-foot (5.47-meter) increments to a 12-inch (30.5-centimeter) top. Sectioning above the 12-inch top

was done at shorter intervals--6 to 10 feet (1.8 to 3 meters)--preferably centered near selected internodes. Where salvage of stem was not required, section cuts above breast height were made at individual discretion, but at *no* greater intervals than where salvage was planned. In addition to the sectioning points, cuts made at a point just below the base of the primary live crown in an area undistorted by branch swell provide information on stem form below and within the crown.

Section cuts were marked by use of a 100-foot steel tape graduated in feet and hundredths of feet. Average stump height was measured and zero end of the tape was placed at base of cut stem (allowing for the width of the stump section if taken from base of stem). Cumulative measurements of stem length were carried as shown in figure 3. Several methods of measuring length were tried. All were discarded in favor of the system shown in figure 3. Best accuracy and, of course, fewer rechecks of down trees were necessary when the cumulative-height-above-stump measurements were obtained before the stem was bucked and sectioned. Bucking of the stem before stem length and diameter measurements are taken is best avoided.



Yellowjacket Creek  
North Bend Ranger District }  
Snoqualmie National Forest }

①  
②

Noble Fir 1 ④ Plot 75 ③  
Established 4/28/68 ⑤  
Felled 8/11/68 ⑥

| Taped Section Intervals          | Stump Height and Cumulative Height Above Ground | Diameter Outside Bark ⑫ | Diameter Inside Bark ⑭ | Single Bark Thickness Measurements |      |      |      |      |      | Remarks  |
|----------------------------------|-------------------------------------------------|-------------------------|------------------------|------------------------------------|------|------|------|------|------|----------|
| Feet                             | Feet                                            | Inches                  | Inches                 | Inches                             |      |      |      |      |      |          |
| Stump                            | ⑦ 1.5                                           | 74.9                    | * ⑦2.30 ④5             | 1.20                               | 1.30 | 1.40 | 1.05 | 1.50 | 1.35 | Ave 1.30 |
| 8.1                              | 3.0 ⑧                                           | 65.8                    | * ⑥2.66                | 1.75                               | 1.55 | 1.15 | 2.10 | 1.40 | 1.45 | Ave 1.57 |
| 21.4                             | 21.4                                            | 54.1                    | 51.75                  |                                    |      |      |      |      |      |          |
| 39.4                             | 39.4                                            | 52.4                    | 50.05                  |                                    |      |      |      |      |      |          |
| 57.3                             | 57.3                                            | 50.5                    | 48.60                  |                                    |      |      |      |      |      |          |
| 75.4                             | 75.4                                            | 48.6                    | 46.50                  |                                    |      |      |      |      |      |          |
| ⑨ 93.4                           | 93.4                                            | 47.5                    | 45.20                  |                                    |      |      |      |      |      |          |
| ⑩ 18.0                           | 111.4                                           | 46.6                    | 43.60                  |                                    |      |      |      |      |      |          |
| 32.0                             | 125.4                                           | Break ⑪                 |                        |                                    |      |      |      |      |      |          |
| 3.8                              | 129.2                                           | 43.1                    | * ③9.86                | 1.80                               | 1.80 | 1.70 | 1.50 | 1.40 | 1.50 | Ave 1.62 |
| 21.8                             | 147.2                                           | * ④2.98 ⑬               | 39.40                  | 1.40                               | 1.50 | 1.55 | 1.95 | 2.15 | 2.20 | Ave 1.79 |
| 39.9                             | 165.3                                           | 38.8                    | 36.00                  |                                    |      |      |      |      |      |          |
| 46.8                             | 172.2                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 12.2                             | 184.4                                           | * ③3.14                 | 29.90                  | 1.65                               | 1.85 | 1.60 | 1.50 | 1.53 | 1.55 | Ave 1.62 |
| 29.1                             | 201.3                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 5.1                              | 206.4                                           | 25.1                    | 22.36                  |                                    |      |      |      |      |      |          |
| 13.3                             | 214.6                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 3.9                              | 218.5                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 10.2                             | 228.7                                           | * ①7.66                 | 15.10                  | 1.20                               | 1.25 | 1.40 | 1.25 | 1.25 | 1.35 | Ave 1.28 |
| 14.0                             | 232.5                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 6.8                              | 239.3                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 2.4                              | 241.7                                           | 12.14                   | 10.45                  |                                    |      |      |      |      |      |          |
| 10.1                             | 249.4                                           | 9.12                    | 7.80                   |                                    |      |      |      |      |      |          |
| 12.8                             | 252.1                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 4.9                              | 257.0                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 1.3                              | 258.3                                           | 5.90                    | 5.06                   |                                    |      |      |      |      |      |          |
| 5.9                              | 262.9                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 1.1                              | 264.0                                           | 3.35                    | 2.93                   |                                    |      |      |      |      |      |          |
| 2.9                              | 265.8                                           |                         |                        |                                    |      |      |      |      |      |          |
| 4.0                              | 266.7                                           | 2.14                    | 1.85                   |                                    |      |      |      |      |      |          |
| 4.6                              | 267.5                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 1.6                              | 269.1                                           | 1.37                    | 1.18                   |                                    |      |      |      |      |      |          |
| 2.3                              | 269.8                                           | Break                   |                        |                                    |      |      |      |      |      |          |
| 1.3                              | ⑬ 271.1                                         | Tip                     |                        |                                    |      |      |      |      |      |          |
| ⑬ Elevation                      |                                                 |                         | 2903 ft                |                                    |      |      |      |      |      |          |
| ⑭ Slope 10 % Aspect              |                                                 |                         | ⑮ SE                   |                                    |      |      |      |      |      |          |
| ⑯ Clear length                   |                                                 |                         | 121.5 ft. above stump  |                                    |      |      |      |      |      |          |
| ⑰ length to main live crown      |                                                 |                         | 121.5 ft. above stump  |                                    |      |      |      |      |      |          |
| ⑱ length to epicormic live crown |                                                 |                         | 121.5 ft. above stump  |                                    |      |      |      |      |      |          |
| ⑲ Crown position                 |                                                 |                         | Dominant               |                                    |      |      |      |      |      |          |
| ⑳ Total height                   |                                                 |                         | 272.6 ft.              |                                    |      |      |      |      |      |          |

\* Measurements in shaded circles are calculated--not directly measured.

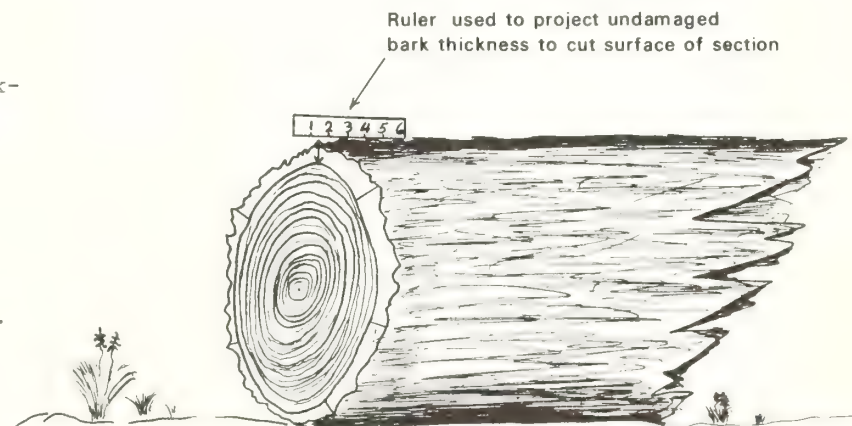
Figure 3.--Sample of field notes taken in waterproof field surveying book for tree measured before it was sectioned.

Explanation of Field Notes (fig. 3)<sup>5/</sup>

1. Plot name--from some local geographic feature or manmade structure such as Lower Cedar River, Humpback Mountain, Yellowjacket Creek, Carpenter Lookout Road, etc.
2. District and Forest.
3. Plot number.
4. Species and tree number.
5. Tree selection date.
6. Tree felling and sectioning (bucking) date.
7. Stump height above average ground level--stump cut was made 1.5 feet above ground on uphill side. However, *recorded* stump height above average ground level was at least equal to 1.5 feet. Usually it was greater because of sloping ground.
8. Cumulative stem length from zero (stump cut).
9. Tape "zeroed" at sectioning point, 93.4 feet above stump. If tape longer than 100 feet is used, "zeroing tape" usually is not required unless stem is broken.
10. Cumulative stem length from tape zero at 93.4-foot section.
11. "Break"--stem is broken at "32.0" from "93.4" tape zero point. Tape is "zeroed" again and cumulative measures continued to next stem "break," etc.
12. Diameter outside bark (d.o.b.) for stump and breast height obtained before tree was felled, and upper stem diameters obtained where bark was undamaged before felled stem was bucked.
13. Where bark was damaged at planned point of sectioning, d.o.b., where circled, was calculated; double of average of six bark thickness measurements was added to the peeled diameter of section. Measurements of bark thickness were taken at approximately 60° intervals on the adjacent, undamaged section cut and/or break. Each bark thickness measurement represents the thickest bark within that 60° arc on the stem at or near the section point. Where end of cut stem was used, a 6-inch rule was used to project undamaged bark surface to cut stem surface for measurement (fig. 4).

<sup>5/</sup> No section at 9 feet above breast height was taken on this example because high quality of stem dictated salvage for peeler logs.

Figure 4.--Six bark thickness measurements were taken at approximately 60° intervals around stem circumference on each section cut or break where d.o.b. could not be obtained because of bark damage.





14. Diameters inside bark (d.i.b.), except where circled, were obtained by "slipping" bark from stem section. This is easily done during the early part of the growing season and soon after felling. Later in the growing season, all bark thickness was measured as described in point 13 because bark could not be easily and completely removed.
15. Diameters inside bark, where circled, were calculated as described in point 13 from double of average of six bark thickness measurements subtracted from d.o.b.
16. Total stem length above stump.
17. Plot elevation from barometric altimeter.
18. Average slope of plot area in percent.
19. Aspect expressed in quadrant or half-quadrant.
20. Clear length above stump--no limbs or knot indicators on bark to point specified. Small epicormic branches 1/4-inch or less in diameter were ignored in determination of clear length.
21. Length to base of live crown above stump--this is to base of primary or main live crown exclusive of all green epicormic or dead branches.
22. Length to base of live crown above stump as defined by beginning of epicormic branches often found on Engelmann spruce and occasionally Douglas-fir.
23. Crown position--"Dominant," "Codominant," etc.
24. Total tree height above average ground level. Each tree selected and felled for stem analysis provided its own individual measurement problems. Not all of the previously described measurement techniques necessarily were used on each tree. In practice, the most efficient combination of measurement techniques that provided accurate data was selected and applied as needed.

## DETAILED SECTIONING MEASUREMENTS, RING COUNTS, AND SEQUENTIAL RADIAL GROWTH MEASUREMENTS

### 1. Before actual sectioning:<sup>6/</sup>

- a. Diameter outside bark was measured at all designated sectioning points. Where bark was damaged or lost, diameters outside bark were taken at equal distances both ways along log from the section cutting mark and averaged (except at stump and breast height). When this distance was greater than twice the diameter at that point, the section d.o.b. was obtained by d.i.b. measurement and individual bark measurements from logs adjacent to section. (See explanatory information relative to fig. 4.)
- b. Cardinal direction upper-stem exposure marks (see fig. 2). Whichever felled stem exposure faces skyward--north, east, south, or west--dictates position of exposure reference marks across all felled stem section points before stem is bucked and sectioned. If tree is bucked before exposure marks are made, this information quite likely will be impossible to collect.

### 2. Sectioning:

Cross sections (disks) 2 to 3 inches thick were cut at all marked stem section points where diameter was larger than 20 inches (fig. 5). Disks

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<sup>6/</sup> If faller worked when measurement crew could not be present, many measurement problems arose. Trees were felled and bucked to length and transverse sections were cut before outside bark diameter and cumulative height measurements were taken. Inaccuracies in diameter and length measurements taken by untrained personnel negated efficiency otherwise derived. However, this type of assembly line production can be used if felling and bucking crews are *carefully* trained.

Figure 5.--Cutting stem section disk from old-growth Douglas-fir.



1 to 2 inches thick were taken from smaller diameter stem sections. Bark was removed completely for d.i.b. measurement. When only a partial section was available because of breakage or bucking difficulties, its diameter was estimated from other associated measurements. A partial section was only acceptable when it contained the pith and a complete radius with an acceptable or "representative" (reasonably normal) ring-growth pattern.

Trees having annual ring pattern destroyed by rot, of course, were rejected. However, where decay was encountered that had not completely obliterated the annual rings, thicker sections of 4 to 6 inches were cut. Decayed sections were carefully handled to prevent breakage. Sandwiching them between strips of 1/4-inch plywood eliminated breakage and loss of information. These later were carefully soaked in water and frozen to facilitate ring counts and measurements

(Herman et al. 1972a, 1972b). Douglass (1928) described an efficient field technique which used a paraffin-gasoline solution to render decayed wood workable. His technique permitted immediate ring counts and sequential radial growth measurements.

### 3. Recommended ring counts and sequential radial growth measurements (fig. 6):

If single ring counts and measurements are to provide data for stem profiles, data collection is relatively uncomplicated. However, if decadal, half-decadal, or other multiple ring measurements are to be taken, counts and sequential radial growth measurements must be taken in a specific manner to provide type of data desired.

At least three different approaches to multiple ring counts are possible:

- a. If desirable to compare tree growth





Figure 6.--Ring counting using large reading glass.

of several trees at selected years in fixed sequence, multiple-ring count must begin at each section circumference and proceed toward the pith. After ring count is completed and ring intervals are marked for each section radius, sequential radial increment measurements are made from the pith and recorded on stem analysis ADP coding form (fig. 11, appendix I). For example, for a tree cut in 1973, decadal count and measurement would provide growth comparison at all section points for 1963, 1953, 1943, and so forth back through time at 10-year intervals.

- b. If desirable to compare tree growth at even chronological decades, decadal ring count also must begin at section circumference and proceed toward the pith. However, modification of procedure is necessary. For example, for trees cut in 1973, if tree growth

comparison is desirable at even decades, i.e., 1970, 1960, 1950, etc., the first multiple-ring count on each section from circumference must span three growth rings to reach an even decade.<sup>7/</sup> For remainder of rings to pith, decadal counts are taken. Sequential radial increment measurements are again made from the pith outward along each established radius.

- c. If desirable to compare growth of trees at specific breast height ages, e.g., at 10-year intervals, a more complicated procedure of ring count and measurement (see footnote 2, p. 3) is necessary than has been described. Decadal counts and measurements for the breast height sections must begin at the *pith*. For example, where decadal ring measurements

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<sup>7/</sup> If the 1973 growth ring is present.

are to be taken, a ring number less than 10 will likely occur as a partial decadal count next to the circumference. The number nine or less will be used to begin ring counts from the circumference on all other sections including the stump. Sequential radial increment measurements again begin at the pith and continue toward the circumference for each radius.

For this paper, the first-described multiple-ring count method--all counts begin at the circumference of each section--is used. The computer program described herein was developed accordingly. Some modification of the program is necessary to produce alternate stem analysis information describing growth at even chronological decades or at specific breast-high age intervals. It should be carefully noted that regardless of selected multiple ring count approach, all sequential growth measurement information is obtained from cumulative multiple annual ring measurements *always* taken from the pith outward toward the circumference of each section. For our computer program, that procedure is necessary to provide growth data for a normal stem profile graph of height over radius.

Unless the tree was extremely out of round or the pith obviously was excessively off geometric center, as is sometimes found in trees on very steep slopes, only one selected radius was taken for sections where longest radius differed from shortest by 10 percent or less. Otherwise, at least two radii--the longest and one about 180° to the longest--were selected. Three radii, the longest and two others about 120° each side of the longest, were taken on stump sections. For our stem analysis studies, that system always resulted in acceptable profiles. Failure to select the proper radii for annual ring counts and measurements will result in unacceptable stem profiles (fig. 15, appendix I).

Successful utilization of stem analysis field and laboratory measurements to produce stem profiles depends on reasonably accurate average radii. There are several ways to determine the average radius (pith to perimeter) of a tree stem cross-section or disk. Because of limited finances and time, selection of "representative" radii was expedient. Most of our trees were old-growth specimens, and the common occurrence of annual ring growth aberrations caused by occluded rot, scars, knots, pitch pockets, etc., usually prevented actual designation of acceptable "true average radii"<sup>8/</sup> from pith to perimeter on stem section disks. Instead, radii were selected that were aberration-free and representative (ocularly) of the radial growth at each section point on the stem. For easy measurement of sequential radial growth from pith to perimeter and avoidance of inaccuracies caused by missing rings (Douglass 1928), the shorter radii from any section were avoided.

When more than one radius per section was measured, sequential increment measurements of each radius were re-proportioned (table 1) and a simple arithmetic average of each re-proportioned radial increment was calculated and coded for

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<sup>8/</sup> Radii derived from halving diameter tape measurements and accepting the small positive bias inherent with the diameter tape method (Matérn 1956).

keypunching (appendix I, fig. 12). Reproportioning was done by the equation:

$$RRIM = \frac{Dib/2}{TAR} (RIM)$$

Where *RRIM* = Reproportioned sequential radial increment measurement

*Dib* = Diameter inside bark of section as determined by diameter tape

*TAR* = Total length of actual measured radius (representative radius)

*RIM* = Sequential increment measurement from representative radius.

Multiple radii were averaged with a desk calculator or by a simple program on a desk-top computer.

A more complicated method of averaging with the quadratic mean approach was

suggested by Matérn (1956). According to Matérn, the quadratic mean of several random radii at each section point provides an unbiased estimate of any area, convex or not, and is applicable to closures such as those projected by tree stem cross-sections. We used available reproportioned multiple radius data, and our resulting average radii differed little from those produced by the quadratic mean approach. The differences were small (usually second and third decimal place) because all measured radii were reproportioned to the section's average radius before they were averaged (table 1).

Reproportionment of sequential radial growth measurements for sections with a single radius is automatically completed by the computer program. Therefore, such sections can be coded and keypunched as measured.

Table 1.--Multiple radius computations for NF1, plot 75

Section: Stump

Single bark thickness: 1.30 inches

Section height above ground: 1.5 feet Section ring count: 437 years

Section d.o.b.: 74.90 inches

| Measured radial data |          |          | Reproportioned radial data |          |          | Average reproportioned radial data |
|----------------------|----------|----------|----------------------------|----------|----------|------------------------------------|
| Radius 1             | Radius 2 | Radius 3 | Radius 1                   | Radius 2 | Radius 3 |                                    |
| 0.78                 | 0.76     | 0.83     | 0.73                       | 0.80     | 0.83     | 0.79                               |
| 1.82                 | 1.69     | 1.80     | 1.71                       | 1.79     | 1.80     | 1.77                               |
| 2.97                 | 2.74     | 2.90     | 2.80                       | 2.90     | 2.91     | 2.87                               |
| 4.41                 | 3.99     | 4.19     | 4.15                       | 4.22     | 4.20     | 4.19                               |
| 5.96                 | 5.38     | 5.65     | 5.61                       | 5.70     | 5.67     | 5.66                               |
| .                    | .        | .        | .                          | .        | .        | .                                  |
| .                    | .        | .        | .                          | .        | .        | .                                  |
| .                    | .        | .        | .                          | .        | .        | .                                  |
| 36.69                | 32.65    | 34.45    | 34.54                      | 34.56    | 34.55    | 34.55                              |
| 37.15                | 33.04    | 34.88    | 34.97                      | 34.98    | 34.98    | 34.98                              |
| 37.62                | 33.46    | 34.32    | 35.42                      | 35.42    | 35.42    | 35.42                              |
| 37.91                | 33.72    | 35.59    | 35.69                      | 35.69    | 35.69    | 35.69                              |
| 38.40                | 34.15    | 36.05    | 36.15                      | 36.15    | 36.15    | 36.15                              |



Production of stem profiles from nonreproportioned measurement data for sections with a single radius, together with those having averages of reproportioned multiple radii, is completed by the computer program described and presented in appendixes II and III. Should automatic reproportionment of all radii, both single and multiple, be desired, a revision of that program is required.

### **RADIAL MEASUREMENTS, SEQUENTIAL RADIAL GROWTH DATA RECORDS, AND SECTION STORAGE**

Where only one radius is required, no field counts or measurements need be taken. A selected or representative radius from a transverse section cut with a small chain saw can be taken from the field for later processing in the office or laboratory (fig. 7). For sections less than 10

inches in diameter, the complete disk should be collected because of difficulty in cutting a radial section.

For both permanent ring count and sequential radial growth records where complete disk sections cannot be taken, counts and measurements on sections requiring multiple radii must be completed in the field. Heavy clear plastic overlays (fig. 8) have been used successfully for permanent ring count and growth records. Douglass (1919) used a similar technique to obtain sequential radial growth records. He used "paper rubbings" for transcribing ring-growth information from transverse radial sections.

Prior to field use, fine parallel lines spaced one-half inch apart were drawn on the transparent plastic with a sharp round point such as a push pin or shortened dissection needle. After any radius on a section was established, counts were made

*Figure 7.--Large transverse disk from sectioned noble fir with the representative radius removed.*





Figure 8.--Tracing radial ring pattern on plastic overlay.

as previously described and decadal or other multiple ring marks were made on the wood with a *hard* sharp-pointed blue lead pencil. A moist surface provided darker and sharper blue pencil marks. For accuracy and uniformity, we recommend that all marks be made so that the edge of the blue pencil line coincides with the *outside* edge of the summer wood for each marked ring. Transcribing these marks to the fine parallel lines on a plastic overlay was relatively simple, again done with a sharp-pointed scribe. Where any radius was longer than a single line on the overlay, a second line, etc., with proper documentation was used for continuation. These plastic overlays were set aside for later checking and measurement and are available for other observations. Scribed marks on the clear plastic are easily seen with a dark-colored background under the plastic.

A transverse section of wood was also

collected, cut with a small chain saw; it contained the best representative radius from sections (stump, b.h., etc.) from which multiple radii were transcribed to plastic. These radial transverse sections were valuable for correcting any errors later encountered.

Identification of sections is extremely important. Aluminum flashing squares (such as those used for referencing and boundary marking during surveying)--with identification scribed by ballpoint pen--were found to be the most durable method of marking wood sections. They were firmly stapled adjacent to and not covering selected radius of each section top. Each section was identified with plot number, tree species, tree number, and stem section location; e.g., "P70 NF1 127.3" means plot 70, noble fir 1, 127.3 feet above stump. "Top" of each section was always identified.



Radial transverse sections and disks for each tree were packaged with fiberglass tape. An identification tag bearing plot, tree number, species, and general location was attached to each package of radial transverse sections (fig. 9).

## Stem Analysis Laboratory and Computer Methods

Annual-ring counts and sequential radial growth measurements not completed in the field were made in the laboratory by the count plan selected. The sequential radial growth marks transcribed in the field to the plastic overlays also were measured according to the selected count plan, and the data were entered on a coding form (fig. 11, appendix I). Data on the coding forms were keypunched on standard 80-column ADP cards.

Sequential radial growth was measured

with a 24-inch machinist rule graduated to the nearest hundredth of an inch except where annual rings were closely spaced. For transverse sections with rings very close together, a dendrochronograph equipped with a traveling binocular zoom microscope was used (fig. 10), and sequential radial growth was measured to the nearest hundredth of a millimeter. To correspond with ruler-measured data for our studies, metric information was converted to inches.

For easier ring counts and measurements along representative radii, the wood surface on stem section disks or radial transverse sections was smoothed with a thin-bladed, chisel-edged, hobby-type razor-knife or was sanded with an electric sander. Sanding with very fine sandpaper usually was done only when narrow growth rings (about 40 or more per inch) were encountered. Douglass (1928) favored the razor-knife method of wood surface preparation over that of

*Figure 9.--Radial transverse sections and disks packaged for laboratory examination. Tag identifies package of sections of white fir, tree number 1, from the Rogue River National Forest.*

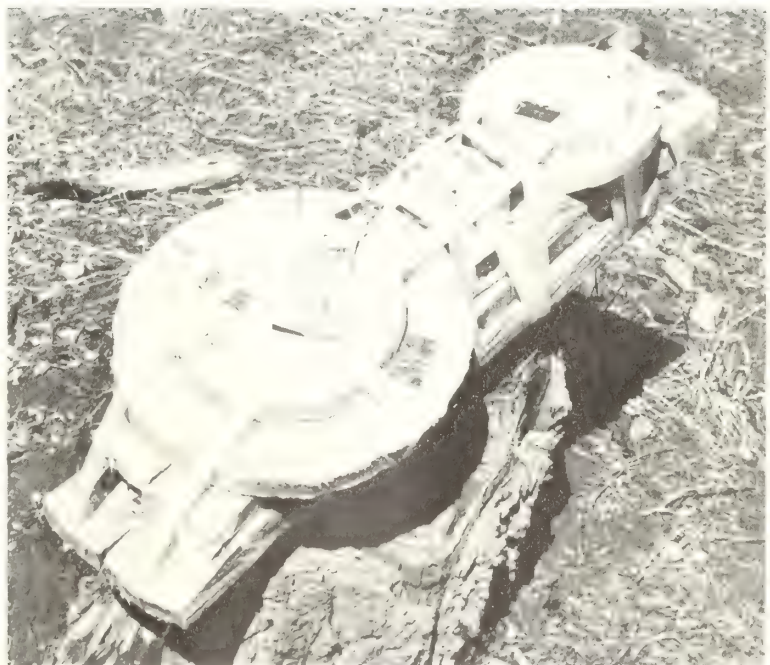




Figure 10.--A dendro-  
chronograph was used  
to measure radial  
growth where annual  
rings were closely  
spaced.

sanding, and our work supported that opinion. To make the annual rings more distinct, we used water for most species. For resinous wood of pines and occasionally Douglas-fir, we found that kerosene or other light oil was the best agent for enhancing the annual rings. Sophisticated wood-staining techniques were unnecessary.

Where there was concern for radial shrinkage in the collected radial sections and transverse disks, the current year's or "green" radii were placed on the plastic overlays in the field. Two marks--pith center and section perimeter edge--were transcribed to these plastic overlays. Before laboratory ring counts and sequential radial growth measurements were taken, green dimensions were restored by soaking the collected specimens in water (Herman and DeMars 1970) for at least 24 hours, then draining them overnight. Radii of green sections that were correctly marked on the plastic

always corresponded closely to those of the water-restored sections. Ring intervals for these field-selected representative radii then were marked off and measured according to the selected count plan.

#### **COMPUTER PROGRAM FOR STEM ANALYSIS DATA**

At least two previous programs using stem analysis data for computing and graphing tree growth are in existence (Brace and Magar 1968, Pluth and Cameron 1971). Both of these automated methods machine-plot derived tree growth parameters. Neither program provides a standard height-radius stem profile as provided in this paper. Both programs provide volume and basal area computations that could be adapted for use with our program.

Preparation for computer production of stem analysis data requires coding of the field and the laboratory data from stem disks and scribed plastic overlays. Figure 12, appendix I, is a stem analysis data code completed for "NF1, plot 75." From data sheets such as these, 80-column ADP cards were keypunched and verified. A computer was programed to produce for each tree: (1) a stem analysis graph (fig. 13, appendix I) using reproportioned radial data and straight-line interpolated heights, (2) listing of reproportioned radial data corresponding to the stem analysis profile, (3) a set of ADP cards punched to contain the reproportioned data, (4) a height-age listing by the selected ring-count interval using straight-line interpolation, (5) a height-age graph of the original tree data, and (6) a set of ADP cards punched to contain the selected ring count interval height-age data.

Any or all of the previous items can be selected as output for an individual tree on a single run. These options are explained in appendix II, card type I.

## EDITING STEM ANALYSIS DATA USING THE COMPUTER PROGRAM

In actual practice, usually only the stem profile was plotted first to discover if any errors existed in the raw data. Such errors (figs. 14 and 15, appendix I) were readily determined and corrections were made to insure that the changes were correct. Following the production of an acceptable stem profile graph, the remaining computer program options were selected for completion. Data editing using the stem profile graph should be done cautiously because not all apparently eccentric profile graph lines are measurement errors. Some line aberrations can be caused by growth problems such as old stem breaks, forks, etc.

\* \* \* \*

A copy of the stem analysis program listing is in appendix III. Further information about the program may be obtained from the Pacific Northwest Forest and Range Experiment Station, P. O. Box 3141, Portland, Oregon 97208.

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## Appendix I

Table 2.--Noble fir and associated species felled and sectioned during stem analysis studies

| Common name                  | Scientific name <sup>1/</sup>                       | Species ADP code  |
|------------------------------|-----------------------------------------------------|-------------------|
| noble fir                    | <i>Abies procera</i> Rehd.                          | 022               |
| Douglas-fir <sup>2/</sup>    | <i>Pseudotsuga menziesii</i> (Mirb.) Franco         | 202               |
| Pacific silver fir           | <i>Abies amabilis</i> (Dougl.) Forbes               | 011               |
| western hemlock              | <i>Tsuga heterophylla</i> (Raf.) Sarg.              | 263               |
| mountain hemlock             | <i>Tsuga mertensiana</i> (Bong.) Carr.              | 264               |
| western white pine           | <i>Pinus monticola</i> Dougl.                       | <sup>3/</sup> 119 |
| grand fir <sup>2/</sup>      | <i>Abies grandis</i> (Dougl.) Lindl.                | <sup>3/</sup> 015 |
| western redcedar             | <i>Thuja plicata</i> Donn.                          | 254               |
| subalpine fir                | <i>Abies lasiocarpa</i> (Hook.) Nutt.               | 019               |
| western larch                | <i>Larix occidentalis</i> Nutt.                     | 073               |
| lodgepole pine               | <i>Pinus contorta</i> Dougl.                        | 108               |
| Engelmann spruce             | <i>Picea engelmannii</i> Parry                      | 093               |
| Shasta red fir <sup>2/</sup> | <i>Abies magnifica</i> var. <i>shastensis</i> Lemm. | 021               |
| ponderosa pine <sup>2/</sup> | <i>Pinus ponderosa</i> Laws.                        | 122               |

<sup>1/</sup> Scientific names follow Elbert L. Little, Jr., Check list of native and naturalized trees of the United States (including Alaska). U.S. Department of Agriculture, Agriculture Handbook 41, 472 p., 1953.

<sup>2/</sup> Species associated with Shasta red fir felled and sectioned south of the known normal range of noble fir. Douglas-fir and grand fir (white fir) were sampled in both the noble fir range and Shasta red fir range.

<sup>3/</sup> Grand fir and white fir considered as single species for this phase of study--both coded "015."



| STEM ANALYSIS DATA |           | Plot no. | Tree no.      | Date felled | Initials |
|--------------------|-----------|----------|---------------|-------------|----------|
| Study no.          | Plot name | Species  | Date measured | Sheet       | of       |
| 08                 |           |          |               |             |          |
| 64                 |           |          |               |             |          |
| 94                 |           |          |               |             |          |
| 22                 |           |          |               |             |          |
| 92                 |           |          |               |             |          |
| 52                 |           |          |               |             |          |
| 42                 |           |          |               |             |          |
| 22                 |           |          |               |             |          |
| 12                 |           |          |               |             |          |
| 02                 |           |          |               |             |          |
| 69                 |           |          |               |             |          |
| 89                 |           |          |               |             |          |
| 29                 |           |          |               |             |          |
| 99                 |           |          |               |             |          |
| 59                 |           |          |               |             |          |
| 49                 |           |          |               |             |          |
| 29                 |           |          |               |             |          |
| 19                 |           |          |               |             |          |
| 09                 |           |          |               |             |          |
| 65                 |           |          |               |             |          |
| 85                 |           |          |               |             |          |
| 25                 |           |          |               |             |          |
| 95                 |           |          |               |             |          |
| 55                 |           |          |               |             |          |
| 45                 |           |          |               |             |          |
| 25                 |           |          |               |             |          |
| 15                 |           |          |               |             |          |
| 05                 |           |          |               |             |          |
| 64                 |           |          |               |             |          |
| 84                 |           |          |               |             |          |
| 24                 |           |          |               |             |          |
| 94                 |           |          |               |             |          |
| 54                 |           |          |               |             |          |
| 44                 |           |          |               |             |          |
| 24                 |           |          |               |             |          |
| 14                 |           |          |               |             |          |
| 04                 |           |          |               |             |          |
| 66                 |           |          |               |             |          |
| 86                 |           |          |               |             |          |
| 26                 |           |          |               |             |          |
| 96                 |           |          |               |             |          |
| 56                 |           |          |               |             |          |
| 46                 |           |          |               |             |          |
| 26                 |           |          |               |             |          |
| 16                 |           |          |               |             |          |
| 06                 |           |          |               |             |          |
| 68                 |           |          |               |             |          |
| 88                 |           |          |               |             |          |
| 28                 |           |          |               |             |          |
| 98                 |           |          |               |             |          |
| 58                 |           |          |               |             |          |
| 48                 |           |          |               |             |          |
| 28                 |           |          |               |             |          |
| 18                 |           |          |               |             |          |
| 08                 |           |          |               |             |          |
| 62                 |           |          |               |             |          |
| 82                 |           |          |               |             |          |
| 22                 |           |          |               |             |          |
| 92                 |           |          |               |             |          |
| 52                 |           |          |               |             |          |
| 42                 |           |          |               |             |          |
| 22                 |           |          |               |             |          |
| 12                 |           |          |               |             |          |
| 02                 |           |          |               |             |          |
| 64                 |           |          |               |             |          |
| 84                 |           |          |               |             |          |
| 24                 |           |          |               |             |          |
| 94                 |           |          |               |             |          |
| 54                 |           |          |               |             |          |
| 44                 |           |          |               |             |          |
| 24                 |           |          |               |             |          |
| 14                 |           |          |               |             |          |
| 04                 |           |          |               |             |          |
| 6                  |           |          |               |             |          |
| 8                  |           |          |               |             |          |
| 4                  |           |          |               |             |          |
| 9                  |           |          |               |             |          |
| 5                  |           |          |               |             |          |
| 4                  |           |          |               |             |          |
| 2                  |           |          |               |             |          |
| 1                  |           |          |               |             |          |

St.Ht. Cumulative Height Above Stump  
 Section Diameters Outside Bark  
 Bark Thickness  
 Age of Section  
 Cumulative Annual Ring Measurement From Pith  
 Cumulative Annual Ring Measurement From Pith @ B.H.  
 Cumulative Annual Ring Measurement From Pith @ Stump  
 Annual Ring Increment  
 Number of Sections Including Tip  
 Card Number  
 Age at Breast Height  
 Diameter Breast Height  
 Species Code  
 Tree Number  
 Plot Number

Figure 11.--Stem analysis data code sheet.

STEM ANALYSIS DATA Plot no. 75 Tree no. 1 Date felled 8/11/68 Initials MA  
 Study no. W61, W63 Plot name Yellow Jacket Creek Species Noble Fir Date measured 8/12/68 Sheet 1 of 2

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| 75 | 1022 | 658 | 432 | 1211 | 15 | 30 | 214 | 394 | 573 | 754 | 934 | 1114 | 1292 | 1472 | 1653 | 1844 | 2064 | 2287 | 2417 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|----|------|-----|-----|------|----|----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|

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Figure 12.--Completed stem analysis data code sheet for noble fir 1, plot 75.





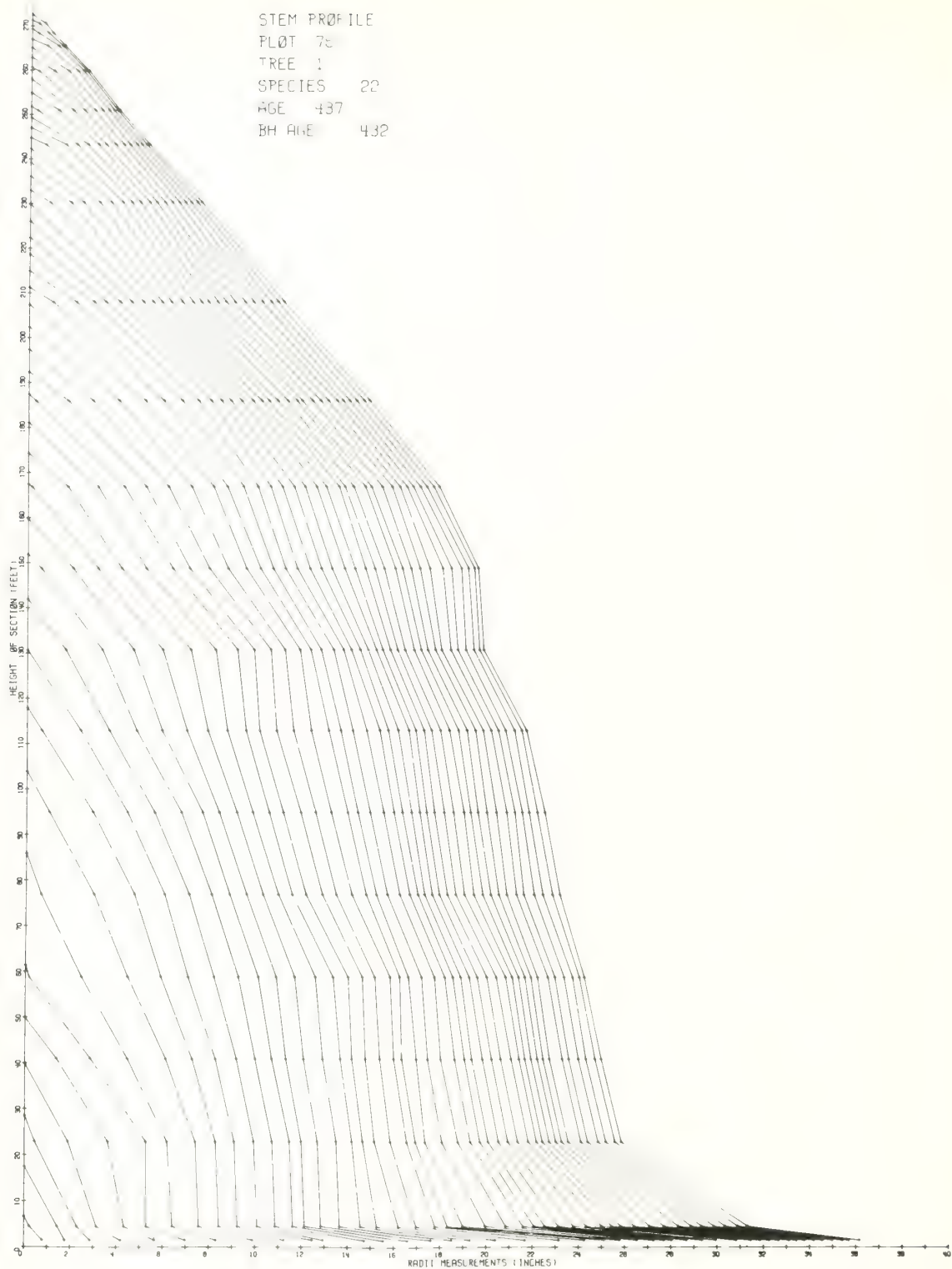


Figure 13.--Computer produced stem profile chart for noble fir 1, plot 75.

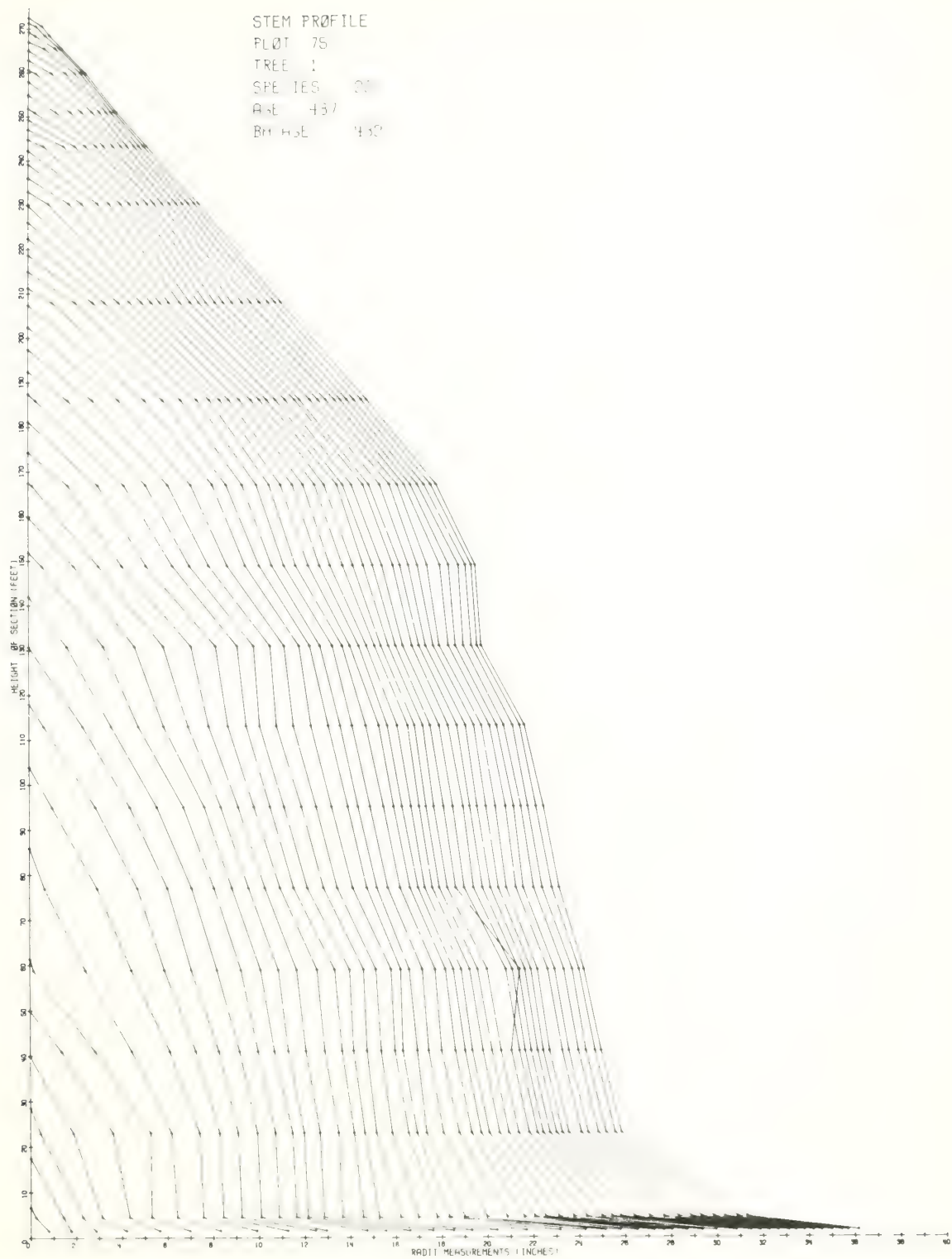


Figure 14.--Computer produced stem profile graph showing error in data.



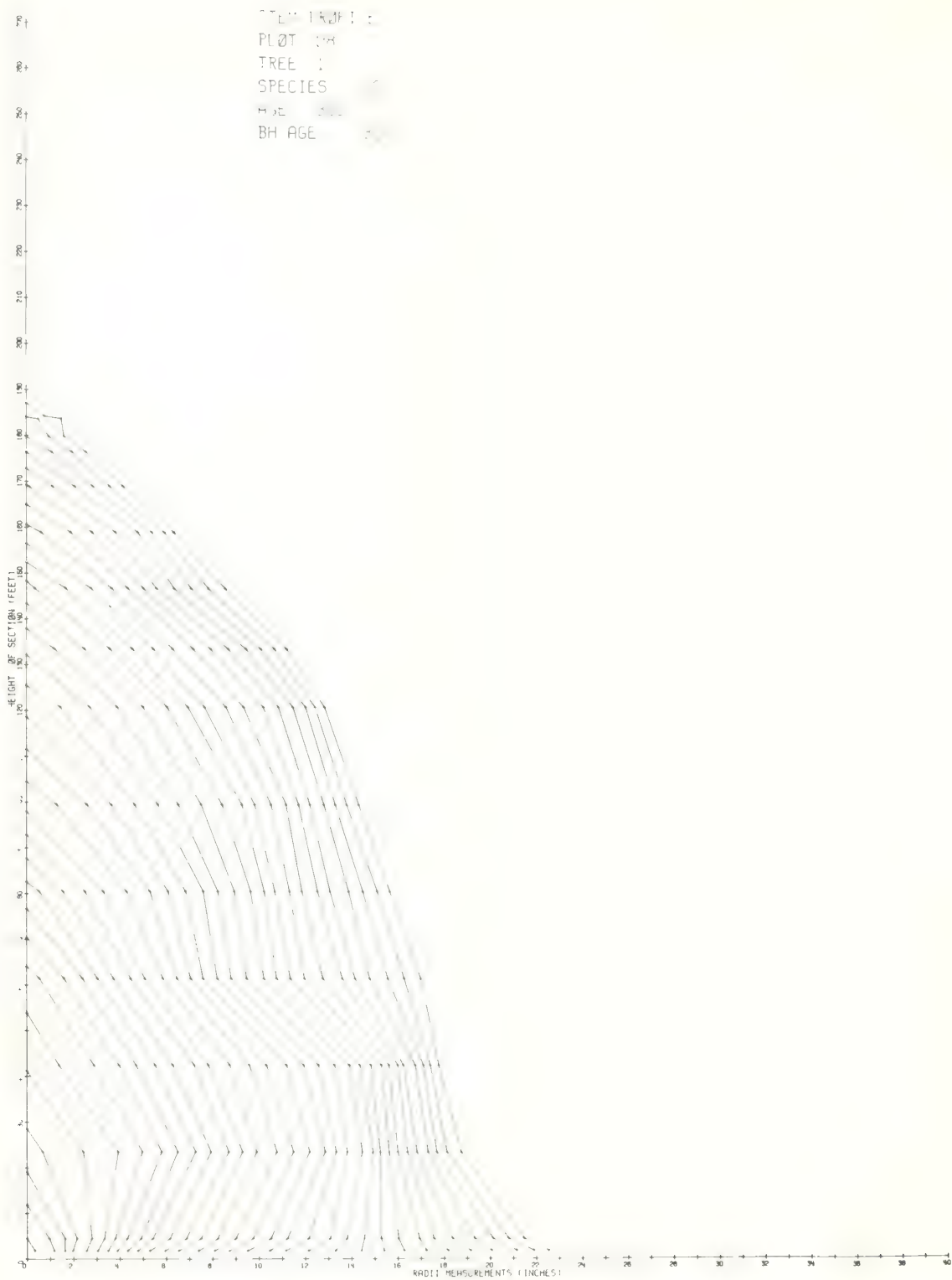


Figure 15.--Computer produced stem profile showing results of inadequate data measurements at lower stem section points.

## Appendix II

### Card Input Formats

With the exception of the "00" card, the program<sup>1/</sup> data input cards can be punched directly from the stem analysis data code sheets (figs. 11 and 12 of appendix I). Descriptive plot and miscellaneous tree information to be punched on the "00" card comes from various places in the original field notes. Transcription of that information into the following format is mandatory.

#### Card Type I--"00" Card

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                        | <u>Special<br/>notes</u>                                                                                |
|-------------------------|--------------------------------------------|----------------------------------------------|---------------------------------------------------------------------------------------------------------|
| 1-3                     | XXX                                        | Plot number                                  |                                                                                                         |
| 4                       | X                                          | Tree number                                  |                                                                                                         |
| 5-7                     | XXX                                        | Species code                                 | Table 2, appendix I                                                                                     |
| 8-11                    | XXX.X                                      | D.b.h. (o.b.)                                | Inches                                                                                                  |
| 12-15                   | XXXX                                       | Breast height ring<br>count                  |                                                                                                         |
| 16-17                   | XX                                         | Card number                                  | Always "00"                                                                                             |
| 18-19                   | XX                                         | Number of sections<br>taken for the tree     | (Including tip,<br>limit--30)                                                                           |
| 20                      | X                                          | Ring count measure-<br>ment interval (years) | 1 = 10 yr<br>5 = 5 yr<br>3 = 1 yr                                                                       |
| 21-22                   | XX                                         | Year cut                                     |                                                                                                         |
| 23-24                   | XX                                         | Crown class                                  | Dominant and tallest<br>on plot--11<br>Dominant--1<br>Codominant--2<br>Intermediate--3<br>Suppressed--4 |
| 25-28                   | XXX.X                                      | Height to first live<br>limb (feet)          | Above average<br>ground level                                                                           |
| 29-32                   | XXX.X                                      | Height to live crown<br>(feet)               | Above average<br>ground level                                                                           |
| 33-36                   | XXX.X                                      | Clear length (feet)                          | Above average<br>ground level                                                                           |
| 37-40                   | XXX.X                                      | Crown length (feet)                          | Above average<br>ground level                                                                           |

---

<sup>1/</sup> Regardless of tree size or age, program is adaptable to data from 30 section points where the 30th section point is the tip having a diameter of "0" and a single bark thickness of "0." Also, program is limited to 80 incremental measurement intervals. Expressed in terms of stump age, program will accommodate an 80-year-old tree at 1-ring measurement intervals, a 400-year-old tree at 5-ring measurement intervals, or an 800-year-old tree at 10-ring measurement intervals.

Card Type I--"00" Card, continued

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                                                       | <u>Special<br/>notes</u>                                                                                                |
|-------------------------|--------------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| 41-45                   | XXXXX                                      | Elevation (feet)                                                            |                                                                                                                         |
| 46                      | X                                          | Blank                                                                       |                                                                                                                         |
| 47                      | X                                          | Aspect                                                                      | Aspect codes<br>Level - 0<br>North, northeast 1,2<br>East, southeast 3,4<br>South, southwest 5,6<br>West, northwest 7,8 |
| 48-50                   | XXX                                        | Slope (percent)                                                             |                                                                                                                         |
| 51-56                   | XXXXX.X                                    | Latitude north                                                              | Cols. 51-53 degrees<br>Cols. 54-56 min                                                                                  |
| 57-62                   | XXXXX.X                                    | Longitude west                                                              | Cols. 57-59 degrees<br>Cols. 60-62 min                                                                                  |
| 63-65                   | XXX                                        | Preliminary noble fir<br>site index                                         | From PNW-119<br>Res. Note 1970 <sup>2/</sup>                                                                            |
| 66-69                   | XXX.X                                      | Total tree height (feet)                                                    |                                                                                                                         |
| 70-74                   | XXXXX                                      | Blank                                                                       |                                                                                                                         |
| 75                      | X                                          | Card output of<br>reproportioned data                                       | To suppress output,<br>punch a "1"; otherwise<br>leave blank.                                                           |
| 76                      | X                                          | Printed output of<br>reproportioned data                                    | To suppress output,<br>punch a "1"; otherwise<br>leave blank.                                                           |
| 77                      | X                                          | Stem profile                                                                | To suppress output,<br>punch a "1"; otherwise<br>leave blank.                                                           |
| 78                      | X                                          | Card output of height-age<br>data by the selected ring<br>count interval    | To suppress output,<br>punch a "1"; otherwise<br>leave blank.                                                           |
| 79                      | X                                          | Printed output of height-age<br>data by the selected ring<br>count interval | To suppress output,<br>punch a "1"; otherwise<br>leave blank.                                                           |
| 80                      | X                                          | Height-age plot of original<br>tree data                                    | To suppress output,<br>punch a "1"; otherwise<br>leave blank.                                                           |

<sup>2/</sup> Donald J. DeMars, Francis R. Herman, and John F. Bell. Preliminary site index curves for noble fir from stem analysis data. USDA Forest Service Research Note PNW-119, 9 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1970.

# Card Type II--Section Height Card

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                              | <u>Special<br/>notes</u>                                                          |
|-------------------------|--------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------------------------|
| 1-3                     | XXX                                        | Plot number                                        |                                                                                   |
| 4                       | X                                          | Tree number                                        |                                                                                   |
| 5-7                     | XXX                                        | Species                                            | See ADP code table 2,<br>appendix I                                               |
| 8-11                    | XXX.X                                      | D. b. h. (o. b. )                                  | Inches                                                                            |
| 12-15                   | XXXX                                       | Breast height age                                  | Years                                                                             |
| 16-17                   | XX                                         | Card number                                        | Card position in<br>tree deck                                                     |
| 18-19                   | XX                                         | Number of sections                                 | (Including tip)                                                                   |
| 20                      | X                                          | Ring count measurement<br>interval                 | limit: 30 or less<br>1 = 10-yr interval<br>5 = 5-yr interval<br>3 = 1-yr interval |
| 21-24                   | XXX.X                                      | Stump height (ft)                                  | Section 1                                                                         |
| 25-28                   | XXX.X                                      | Height above the stump<br>of breast height section | Section 2                                                                         |
| 29-32                   | XXX.X                                      | Height above the stump<br>of section 3             | Section 3                                                                         |
| 33-36                   | XXX.X                                      | Height above the stump<br>of section 4             | Section 4                                                                         |
| .                       | .                                          | .                                                  | .                                                                                 |
| .                       | .                                          | .                                                  | .                                                                                 |
| .                       | .                                          | .                                                  | .                                                                                 |
| 77-80                   | XXX.X                                      | Height above the stump<br>of section 15            | Section 15                                                                        |

Up to 15 section heights can be punched on one computer card, and the program can process up to 30 section heights for any one tree. The additional section heights are punched on a continuation card (same format as above) with section 16 height data entered in columns 21-24. It should be noted that the tip height measurement is considered one section. Columns 1 to 20 of the continuation card will be a duplicate of the previous card except for columns 16 and 17 which will contain the card's position number in the tree deck.



### Card Type III--Section Diameter (Outside Bark) Card

For every section height, a corresponding diameter outside bark is needed (tip height diameter equals zero).

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                | <u>Special<br/>notes</u>      |
|-------------------------|--------------------------------------------|--------------------------------------|-------------------------------|
| 1-15                    | (Same as section height card)              |                                      |                               |
| 16-17                   | XX                                         | Card number                          | Card position in<br>tree deck |
| 18-20                   | (Same as section height card)              |                                      |                               |
| 21-24                   | XX.XX                                      | D. o. b. of stump section            | Section 1                     |
| 25-28                   | XX.XX                                      | D. o. b. of breast height<br>section | Section 2                     |
| 29-32                   | XX.XX                                      | D. o. b. of section 3                | Section 3                     |
| 33-36                   | XX.XX                                      | D. o. b. of section 4                | Section 4                     |
| .                       | .                                          | .                                    | .                             |
| .                       | .                                          | .                                    | .                             |
| .                       | .                                          | .                                    | .                             |
| 77-80                   | XX.XX                                      | D. o. b. of section 15               | Section 15                    |

If the number of section heights (including tip height) exceeds 15, a continuation card will be necessary with the diameter outside bark of the 16th section entered in columns 21-24. The first 20 columns of the continuation card will be identical to the previous card except columns 16 and 17 will contain the card's position number in the tree deck.

### Card Type IV--Single Bark Thickness Card

For every section height a corresponding single bark-thickness is needed (tip height bark thickness equals zero).

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                             | <u>Special<br/>notes</u>      |
|-------------------------|--------------------------------------------|---------------------------------------------------|-------------------------------|
| 1-15                    | (Same as section height card)              |                                                   |                               |
| 16-17                   | XX                                         | Card number                                       | Card position in<br>tree deck |
| 18-20                   | (Same as section height card)              |                                                   |                               |
| 21-24                   | XX.XX                                      | Single bark thickness of<br>stump section         | Section 1                     |
| 25-28                   | XX.XX                                      | Single bark thickness of<br>breast height section | Section 2                     |
| 29-32                   | XX.XX                                      | Single bark thickness of<br>section 3             | Section 3                     |
| 33-36                   | XX.XX                                      | Single bark thickness of<br>section 4             | Section 4                     |
| .                       | .                                          | .                                                 | .                             |
| .                       | .                                          | .                                                 | .                             |
| .                       | .                                          | .                                                 | .                             |
| 77-80                   | XX.XX                                      | Single bark thickness of<br>section 15            | Section 15                    |

If the number of section heights (including tip height) exceeds 15, a continuation card will be necessary with the single bark thickness of the 16th section entered in columns 21-24. The first 20 columns of the continuation card will be identical to the previous card except columns 16 and 17 will contain the card's position number in the tree deck.

### Card Type V--Section Ring Count

For every section height a corresponding section ring count is needed (tip height ring count equals zero).

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                  | <u>Special<br/>notes</u>      |
|-------------------------|--------------------------------------------|----------------------------------------|-------------------------------|
| 1-15                    | (Same as section height card)              |                                        |                               |
| 16-17                   | XX                                         | Card number                            | Card position in<br>tree deck |
| 18-20                   | (Same as section height card)              |                                        |                               |
| 21-24                   | XXXX                                       | Ring count of stump section            | Section 1                     |
| 25-28                   | XXXX                                       | Ring count of breast<br>height section | Section 2                     |
| 29-32                   | XXXX                                       | Ring count of section 3                | Section 3                     |
| 33-36                   | XXXX                                       | Ring count of section 4                | Section 4                     |
| .                       | .                                          | .                                      | .                             |
| .                       | .                                          | .                                      | .                             |
| .                       | .                                          | .                                      | .                             |
| 77-80                   | XXXX                                       | Ring count of section 15               | Section 15                    |

If the number of section heights (including tip height) exceeds 15, a continuation card will be necessary with the ring count of the 16th section entered in columns 21-24. The first 20 columns of the continuation card will be identical to the previous card except columns 16 and 17 will contain the card's position number in the tree deck.

### Card Type VI--Sequential Radial Increment Measurements Card

The remainder of the tree data deck consists of card type VI. The format for this card is:

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                                      | <u>Special<br/>notes</u>      |
|-------------------------|--------------------------------------------|------------------------------------------------------------|-------------------------------|
| 1-15                    | (Same as section height card)              |                                                            |                               |
| 16-17                   | XX                                         | Card number                                                | Card position in<br>tree deck |
| 18-20                   | (Same as section height card)              |                                                            |                               |
| 21-24                   | XX.XX                                      | Radial increment measure-<br>ments for stump section       | Section 1                     |
| 25-28                   | XX.XX                                      | Radial increment measure-<br>ments for stump section       | Section 2                     |
| 29-32                   | XX.XX                                      | Radial increment measure-<br>ments for stump section 3     | Section 3                     |
| 33-36                   | XX.XX                                      | Radial increment measure-<br>ments for stump section 4     | Section 4                     |
| .                       | .                                          | .                                                          | .                             |
| .                       | .                                          | .                                                          | .                             |
| .                       | .                                          | .                                                          | .                             |
| 77-80                   | XX.XX                                      | Radial increment measure-<br>ments for stump<br>section 15 | Section 15                    |

If the number of section heights (including tip height) exceeds 15, a continuation card will be necessary with the radial increment measurement of the 16th section entered in columns 21-24. The first 20 columns of the continuation card will be identical to the previous card, except columns 16 and 17 will contain the card's position number in the tree deck.

## Coding Format Layout Determination

Before card type VI can be punched, the radial increment data must be recorded on stem analysis data forms in a manner similar to that shown in figure 12 of appendix I, and as follows:

1. Calculate the total number of lines needed to record the stump radial measurements.

$$\text{Number of lines} = \frac{\text{Ring count of stump section (years)}}{\text{Ring count interval (years)}}$$

If the answer is not a whole number, round the answer up to the next whole number. Figure 12 example:  $437/10 = 43.7$ . Next whole number; in this instance, 44 lines. Any decimal except .0 requires such rounding.

2. Calculate the number of lines needed to record the radial measurements for the 16th section (if there is a 16th section). If the 16th section is the tip, then one line is required to record the needed zero. Figure 12 example:  $93/10 = 9.3$ . Round up to 10 lines.
3. Calculate the total number of lines that will be needed for the tree. Total number of lines = number of lines used for heights, diameter, age, and bark + number of lines needed for stump section + number of lines needed for 16th section. Figure 12 example:  $8 + 44 + 10 = 62$  lines.
4. In columns 16 and 17 of the stem analysis data coding forms, number the lines consecutively up to the total number of lines calculated in item 3. Use additional forms if needed.
5. Calculate the line number where the first radial measurement of section 16 will be recorded.

Line number = Total number of lines - [(number of lines needed for section 16) - 1] \* 2 (asterisks used in computer coding format layout determination formulas mean "*multiplied by*." )

Figure 12 example:  $62 - (10-1) * 2 = 44$

6. Starting on the line calculated in item 5 and skipping every other line, record the radial increment measurements for the 16th section in columns 21-24 of the data forms. Last entry for section 16 should fall on line 62.
7. For all sections above the 16th section, calculate the line number where each section's first radial measurement will be recorded on the data forms. This calculation is as follows:

Line number for section "i" = Total number of lines - [(number of lines needed for section "i") - 1] \* 2

Where:

The number of lines needed for section "i" is calculated by the formula in item 1.

Figure 12 example for section 17: Line number =  $62 - [(7-1) * 2] = 50$

8. Starting on the line number calculated for section "i" in item 7, record section "i's" radial increment measurement data on every other line in the appropriate columns of the data forms.



9. Radial increment measurements for the stump section will begin on the line immediately following the last section ring count line (card type V) and will be recorded on consecutive lines until the first measurement of section 16 is encountered in columns 21-24 of the data form. When this occurs, subsequent radial measurements will be recorded on every other line until completion of the stump measurements.
10. For any "k" section 2 through 15, the beginning line number can be calculated by the following formula:  
 Line number = Total number of lines - (Lines required for 16th section) - (Lines required to record section "k") + 1: Where the number of lines needed for section "k" is calculated by the formula in item 1.  
 Figure 12 example -- Section 2: Line number =  $62 - 10 - 44 + 1 = 9$   
 -- Section 3: Line number =  $62 - 10 - 42 + 1 = 11$
11. Record sections 2 through 15 beginning on the proper line number (as calculated in item 10) for the section being measured. *Remember* that all lines that have section 16 recorded on them will be skipped when recording sections 2 through 15. Because the above instructions are involved, we recommend that figure 12 of appendix I be studied for a full understanding of the proper format for the program input cards.

### Program Output

Program output consists of punched card output as well as printed output. An example of printed output is shown in figures 16 and 17 of this appendix.

Two card decks are produced for each tree. One deck contains the rescaled sequential radial increment data and the other contains the age-height-site index information. The rescaled sequential radial increment deck has a format identical to the input card format.

The format for the age-height-site index output card is:

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>        | <u>Special<br/>notes</u>                                                   |
|-------------------------|--------------------------------------------|------------------------------|----------------------------------------------------------------------------|
| 1-2                     | XX                                         | Study                        |                                                                            |
| 3-6                     | XXXX                                       | Project                      |                                                                            |
| 7-10                    | XXXX                                       | Species code                 | See table 2, appendix I                                                    |
| 11-13                   | XXX                                        | Plot number                  |                                                                            |
| 14-16                   | XXX                                        | Tree number                  |                                                                            |
| 17-18                   | XX                                         | Composite tree (normally 1)  | 1 = single tree,<br>2 or greater =<br>composite tree used<br>for averaging |
| 19-22                   | XXXX                                       | Stump age                    |                                                                            |
| 23-26                   | XXXX                                       | Total breast height age      |                                                                            |
| 27-30                   | XXXX                                       | Site index at b. h., age 100 | Blank if tree is less<br>than 100 years at b. h.                           |

| <u>Card<br/>columns</u> | <u>Implied<br/>decimal<br/>designation</u> | <u>Identification</u>                                 | <u>Special<br/>notes</u>                                                   |
|-------------------------|--------------------------------------------|-------------------------------------------------------|----------------------------------------------------------------------------|
| 31-34                   | XXXX                                       | Height above breast height                            | Interpolated values<br>for each decadal<br>ring count interval<br>multiple |
| 35-38                   | XXXX                                       | Cumulative breast height<br>age by successive decades | Decadal multiples of<br>ring count measure-<br>ment interval               |
| 39-46                   | XXXXXXXXX                                  | Blank                                                 |                                                                            |
| 47-49                   | XXX                                        | Number of cards in this<br>tree's site index deck     |                                                                            |
| 50-80                   |                                            | Blank                                                 |                                                                            |

| ST | PRO | SPE | PLOT | TREE | C STUMP<br>T AGE | B.H.<br>AGE | SITE<br>-4.5 | HEIGHT<br>-4.5 | CUM<br>B.H.<br>AGE | CARD |
|----|-----|-----|------|------|------------------|-------------|--------------|----------------|--------------------|------|
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 13.32          | 10                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 21.77          | 20                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 33.02          | 30                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 43.36          | 40                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 53.31          | 50                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 76.90          | 60                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 96.40          | 70                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 110.34         | 80                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 123.66         | 90                 | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 135.20         | 100                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 145.77         | 110                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 153.54         | 120                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 161.51         | 130                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 168.44         | 140                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 175.26         | 150                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 181.30         | 160                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 186.90         | 170                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 191.90         | 180                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 196.30         | 190                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 201.90         | 200                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 206.00         | 210                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 209.72         | 220                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 213.43         | 230                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 217.15         | 240                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 223.57         | 250                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 224.58         | 260                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 227.97         | 270                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 230.36         | 280                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 234.06         | 290                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 237.15         | 300                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 239.83         | 310                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 242.10         | 320                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 244.56         | 330                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 246.71         | 340                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 249.78         | 350                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 252.84         | 360                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 255.74         | 370                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 257.53         | 380                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 260.12         | 390                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 262.16         | 400                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 264.21         | 410                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 266.50         | 420                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 267.85         | 430                | 44   |
| I  |     | 22  | 75   | I    | I 437            | 432         | 135.20       | 269.10         | 432                | 44   |

Figure 16.--Height-age-site index written output.

DBH= 65.8 . B.H. AGE= 432 CROWN CLASS= 11 HEIGHT TO FIRST LIVE LIMB=123.0 HEIGHT TO LIVE CROWN=123.0  
PRELIMINARY NOBLE FIR SITE INDEX=141 CLEAR LENGTH=123.0 CROWN LENGTH=149.6 TOTAL TREE HEIGHT= 272.6  
ELEVATION= 2903 ASPECT= 4 SLOPE= 10% LATITUDE NORTH= 46 DEG 17.0 MIN LONGITUDE WEST= 121 DEG 50.6 MIN

PLOT NO. 75 SPECIES = 22 TREE NO. 1

| STAYT ** | DISTANCE FROM STUMP |       |       |       | DISTANCE FROM STUMP |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
|----------|---------------------|-------|-------|-------|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| 1.5      | 3.0                 | 21.4  | 19.4  | 57.3  | 75.4                | 93.4  | 111.4 | 129.2 | 147.2 | 165.3 | 184.4 | 206.4 | 223.7 | 241.7 | 249.4 | 256.3 | 264.0 | 266.9 | 271.2 |     |
| DATA OB  | 74.9                | 65.8  | 54.1  | 52.4  | 50.5                | 48.6  | 47.5  | 46.6  | 43.1  | 43.0  | 38.8  | 33.1  | 25.1  | 17.6  | 12.1  | 9.1   | 5.9   | 3.3   | 2.1   | 1.4 |
| MARK     | 1.30                | 1.57  | 1.16  | 1.18  | .95                 | 1.05  | 1.15  | 1.50  | 1.62  | 1.79  | 1.40  | 1.62  | 1.37  | 1.28  | .84   | .66   | .42   | .21   | .14   | .10 |
| AGE      | 437                 | 432   | 415   | 399   | 381                 | 374   | 366   | 354   | 340   | 324   | 301   | 273   | 229   | 169   | 127   | 93    | 64    | 34    | 23    | 16  |
| 1.538    | .79                 | .23   |       |       |                     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.548    | 1.77                | 1.44  |       |       |                     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.558    | 2.87                | 2.30  | .64   |       |                     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.568    | 4.19                | 3.14  | 1.88  |       |                     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.578    | 5.66                | 4.33  | 3.62  | 1.37  |                     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.588    | 6.98                | 5.30  | 5.28  | 2.85  | .15                 |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.598    | 8.31                | 6.42  | 6.19  | 4.46  | 2.45                | .66   |       |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.608    | 9.90                | 7.56  | 7.42  | 6.13  | 4.46                | 2.98  | 1.30  |       |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.618    | 11.25               | 8.44  | 8.30  | 7.28  | 5.91                | 4.75  | 2.33  | .65   |       |       |       |       |       |       |       |       |       |       |       |     |
| 1.628    | 14.46               | 9.24  | 9.10  | 8.29  | 7.09                | 6.06  | 4.43  | 2.37  | 1.69  |       |       |       |       |       |       |       |       |       |       |     |
| 1.638    | 18.09               | 9.95  | 9.20  | 8.22  | 7.13                | 5.62  | 3.62  | 3.62  | 3.62  | 3.30  | .61   |       |       |       |       |       |       |       |       |     |
| 1.648    | 17.72               | 10.87 | 10.74 | 10.01 | 9.28                | 8.12  | 6.79  | 4.82  | 4.77  | 4.67  | 2.01  |       |       |       |       |       |       |       |       |     |
| 1.658    | 15.55               | 11.63 | 11.49 | 10.73 | 10.15               | 8.30  | 7.71  | 5.93  | 5.94  | 5.94  | 3.10  | .18   |       |       |       |       |       |       |       |     |
| 1.668    | 12.14               | 12.00 | 12.11 | 11.74 | 10.37               | 8.44  | 7.93  | 7.01  | 7.01  | 7.01  | 4.14  | 1.76  |       |       |       |       |       |       |       |     |
| 1.678    | 17.60               | 12.84 | 12.70 | 12.11 | 11.87               | 11.03 | 9.90  | 8.26  | 8.26  | 8.26  | 5.20  | 3.08  | .33   |       |       |       |       |       |       |     |
| 1.688    | 18.51               | 13.66 | 13.51 | 12.95 | 12.53               | 11.03 | 9.90  | 8.26  | 8.26  | 8.26  | 5.20  | 3.08  | 1.76  |       |       |       |       |       |       |     |
| 1.698    | 19.30               | 14.57 | 14.42 | 13.71 | 13.41               | 11.63 | 10.62 | 9.59  | 9.21  | 9.21  | 6.36  | 4.04  | 2.84  |       |       |       |       |       |       |     |
| 1.708    | 20.40               | 15.27 | 14.66 | 14.21 | 14.06               | 12.23 | 11.24 | 10.18 | 9.94  | 9.94  | 7.11  | 5.20  | 1.76  |       |       |       |       |       |       |     |
| 1.718    | 21.69               | 16.21 | 15.17 | 14.79 | 14.47               | 12.95 | 12.00 | 10.93 | 10.67 | 10.67 | 7.97  | 6.18  | 2.84  |       |       |       |       |       |       |     |
| 1.728    | 23.15               | 16.98 | 15.86 | 15.42 | 15.21               | 13.55 | 12.65 | 11.67 | 11.28 | 11.28 | 8.79  | 7.19  | 4.00  |       |       |       |       |       |       |     |
| 1.738    | 24.25               | 17.79 | 16.58 | 16.02 | 15.87               | 14.22 | 13.32 | 12.44 | 11.94 | 11.94 | 9.58  | 8.15  | 5.15  |       |       |       |       |       |       |     |
| 1.748    | 25.12               | 18.33 | 16.55 | 16.37 | 16.29               | 14.84 | 14.04 | 13.20 | 12.41 | 10.20 | 8.75  | 5.96  | 1.66  |       |       |       |       |       |       |     |
| 1.758    | 25.78               | 19.01 | 17.37 | 17.00 | 16.57               | 15.28 | 14.48 | 13.72 | 12.86 | 10.75 | 9.46  | 6.76  | 2.08  |       |       |       |       |       |       |     |
| 1.768    | 26.52               | 19.98 | 1     |       |                     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |     |

Figure 17. --Rescaled radial increment written output.





**Appendix III**  
**Stem Analysis Program Listing**

```

PROGRAM NOBLE (INPUT,OUTPUT,PUNCH,TAPE8,TAPE5=INPUT,TAPE6=OUTPUT,
1TAPE7=PUNCH)
 DIMENSION HT(31),DIA(31),BT(31),IAGE(31),RADII(80,31),AGAS(31),
1AGABH(31),HTABH(31),HTTYI(80),IP(31),GRAD(80),RESCL(31,80),IRL(31,
280),KHT(80),JH(80),JD(80),JB(80)
3,XAX1(3),XAX2(3),YAX1(3),YAX2(3),BUF(2000),
4CHT(31)
 DATA YAX1 /30H HEIGHT OF SECTION (FEET) /
 DATA YAX2 /30H TOTAL HEIGHT OF TREE (FEET) /
 DATA XAX1 /30H RADII MEASUREMENTS (INCHES) /
 DATA XAX2 /30H AGE AT STUMP (YEARS) /
 ISKIP=0
 IF(ISKIP.EQ.1) GO TO 794
 CALL PLOTS(BUF,2000,8)
 CALL SYMBOL (0.,0.,.05,3,0.0,-1)
 CALL PLOT (2.,1.,-3)
794 CALL ZSUPRS
 CALL FZSUPR
 ISKIP=1
 1 CONTINUE

C
C READ *00* CARD
C
 READ(5,1572)IHP,IHT,IHS,IHDBH,JX,IHC,IHSEC,IHAI,YCUT,CRL,Z1,Z2,Z3
1,Z4,Z5,Z6,Z7,Z8,ELEV,ASP,HSLOP,NLAT,NLONG,PNFSI,NERHT,ISCRD,
2ISFNT,ISSPT,IHACRD,IHAPNT,IHAPT
1572 FORMAT(I3,I1,I3,2I4,2I2,I1,F2.0,F2.0,4(A3,A1),F5.0,F2.0,F3.0,2I6,
1A3,I4,5X,6I1)
 IF(EOF,5)9000,88
 88 CONTINUE
 YYCUT=1900.+YCUT

C
C ZERO ARRAYS
C
 DO 134 NAO=1,80
 DO 136 NAP=1,31
 HT(NAP)=DIA(NAP)=BT(NAP)=AGAS(NAP)=AGABH(NAP)=HTABH(NAP)=0.
 IAGE(NAP)=IP(NAP)=0
 RADII(NAO,NAP)=RESCL (NAP,NAO)=0.0
 IRL(NAP,NAO)=0
 HTTYI(NAO)=GRAD(NAO)=0.0
 KHT(NAO)=JH(NAO)=JD(NAO)=JB(NAO)=0
 136 CONTINUE
 134 CONTINUE

C
C READ HEIGHTS OF SECTIONS
C
 READ(5,1000)IPLT,ITREE,ISP,DBH,IA,ISEC,IAI,(HT(I),I=1,15)
1000 FORMAT(I3,I1,I3,F4.1,I4,2X,I2,I1,15F4.1)
 IF(ISEC.GT.15)2,3
 2 READ(5,1001)(HT(I),I=16,30)
1001 FORMAT(20X,15F4.1)

```

```

C
C READ DIAMETERS OUTSIDE BARK OF SECTIONS
C
 3 READ(5,1002) (DIA(J),J=1,15)
1002 FORMAT(20X,15F4.2)
 IF (ISEC.GT.15) 4,5
 4 READ(5,1002) (DIA(J),J=16,30)
C
C READ BARK THICKNESS (SINGLE BARK THICKNESS)
C
 5 READ(5,1002) (BT(K),K=1,15)
 IF (ISEC.GT.15) 6,7
 6 READ(5,1002) (BT(K),K=16,30)
C
C READ SECTION RING COUNT
C
 7 READ(5,1003) (IAGE(L),L=1,15)
1003 FORMAT(20X,15I4)
 IF (ISEC.GT.15) 8,9
 8 READ(5,1003) (IAGE(L),L=16,30)
 9 IF (IAI.EQ.1) XINCR=10.
 IF (IAI.EQ.5) XINCR=5.
 IF (IAI.EQ.3) XINCR=1.
 XAGE=IAGE(1)
C
C READ MEASURED RADII OF SECTIONS
C
 JAC=XAGE/XINCR
 EXST=XAGE-(JAC*XINCR)
 IF (EXST.GT.0) JAC=JAC+1
 JAB=IAGE(16)/XINCR
 EXTRA=IAGE(16)-(JAB*XINCR)
 IF (EXTRA.GT.0) JAB=JAB+1
 NNON=JAC-JAB
 DO 10 M=1,80
 READ(5,1004) CHECK,(RADII(M,N),N=1,15)
1004 FORMAT(15X,F2.0,3X,15F4.2)
 IF (CHECK.EQ.99.) GO TO 100
 IF (ISEC.GT.15) 11,10
 11 IF (M.GT.NNON) 71,10
 71 READ(5,1004) CHECK,(RADII(M,N),N=16,30)
 IF (CHECK.EQ.99.) GO TO 100
 10 CONTINUE
C
C CALCULATE NUMBER OF CARDS
C
 100 CARDS=XAGE/XINCR
 ICARD=CARDS
 XPAGE=IAGE(2)
 CRDS=XPAGE/XINCR
 ICRDS=CRDS
 IF (CRDS-ICRDS) 138,138,139
 139 ICRDS=ICRDS+1
 138 IF (CARDS-ICARD) 13,13,12
 12 ICARD=ICARD+1

```

```

C
C CALCULATE AGE OF TREE AT A GIVEN HEIGHT ABOVE STUMP
C AND BREAST HEIGHT
C
13 DO 14 IJ=1,ISEC
 IIJ=IJ+1
 AGAS(IJ)=IAGE(1)-IAGE(IJ)
 AGABH(IJ)=IAGE(2)-IAGE(IIJ)
C
C CALCULATE HEIGHT ABOVE BREAST HEIGHT
C
 HTABH(IJ)=HT(IIJ)-HT(2)
14 CONTINUE
C
C CALCULATE HEIGHTS ABOVE BREAST HEIGHT AT SELECTED YEAR INTERVALS.
C
 NOSEC=1
 IY=XINCR+.05
 NX=IAGE(2)/IY+1
 AXL=NX*IY- IAGE(2)
 IF(AXL.EQ.IY) NX=NX-1
 DO 15 IK=1,NX
 IF(IK.EQ.NX) GO TO 16
 COAGE=XINCR*IK
784 IF(COAGE.GT.AGABH(NOSEC)) 782,783
782 NOSEC=NOSEC+1
 GO TO 784
783 HTINT=HTABH(NOSEC)-HTABH(NOSEC-1)
 AGINT=AGABH(NOSEC)-AGABH(NOSEC-1)
 DIF=COAGE-AGABH(NOSEC-1)
 HTADD=(DIF/AGINT)*HTINT
 HTTYI(IK)=HTABH(NOSEC-1)+HTADD
 GO TO 115
16 HTTYI(IK)=HTABH(ISEC-1)
115 KHT(IK)=HTTYI(IK)+.5
15 CONTINUE
C
C CALCULATE RESCALE OF RADII FOR INDIVIDUAL SECTIONS
C
 DO 17 ILL=1,ISEC
 IF(ILL.EQ.ISEC) GO TO 17
20 DO 19 IXD=1,ICARD
 IC=ICARD
 IP(ILL)=ICARD
 CRAD(ILL)=(DIA(ILL)-2.*BT(ILL))/2.
 RESCL(ILL,IXD)=(CRAD(ILL)/RADII(IC,ILL))*RADII(IXD,ILL)
19 IRL(ILL,IXD)=RESCL(ILL,IXD)*100.+5
17 CONTINUE
 IF(IHAPNT.GT.0)GO TO 1601
 WRITE(6,1102)
1102 FORMAT(1H1,54X,3HCUM/24X,35HC STUMP B.H. SITE HEIGHT B.H. /
173H ST PRO SPE PLOT TREE T AGE AGE -4.5 -4.5 AGE
2 CARDS /)
1601 CONTINUE
 DO 23 KIX=1,IC
 MAGE=KIX*XINCR
 IF(MAGE.GT.IAGE(2))MAGE=IAGE(2)

```

```

C
C PUNCH OUT SITE INDEX CARD
C
 NS=0
 SKKHER=HTTYI(10)
 IF(IAGE(2).LT.100)SKKHER=0.
 KKHER=KHT(10)
 IF(IAGE(2).LT.100)KKHER=0
 IF(IHACRD.GT.0)GO TO 1602
 WRITE(7,1100)NS,ISP,IPL0T,ITREE,IAGE(1),IAGE(2),KKHER, KHT(KIX),
 IMAGE,ICRDS
1100 FORMAT(2H 1,2I4,2I3,2H 1,5I4,8X,I3)
1602 CONTINUE
 IF(IHAPNT.GT.0)GO TO 1603
11015 WRITE(6,1101)NS,ISP,IPL0T,ITREE,IAGE(1),IAGE(2),SKKHER, HTTYI(KI
 IX),MAGE,ICRDS
1101 FORMAT(2H 1,4I5,3H 1,I5,I6,2F8.2,I6,8X,I6)
1603 CONTINUE
 IF(MAGE.EQ.IAGE(2)) GO TO 22
 23 CONTINUE
 22 CONTINUE
C
C WRITE AND PUNCH OUT INFORMATION ON RESCALE
C
 HERHT=NERHT*.1
 HLONG=NLONG*.1
 HLAT=NLAT*.1
 DHDBH=IHDBH*.1
 ZLONG=NLONG*.001
 ZLAT=NLAT*.001
 JLON=ZLONG
 JLAT=ZLAT
 ZLONG=JLON*100.0
 ZLAT=JLAT*100.0
 ZLATM=HLAT-ZLAT
 ZLONGM=HLONG-ZLONG
 HLAT=JLAT
 HLONG=JLON
 IF(ISPNT.GT.0)GO TO 1604
 WRITE(6,1573)DHDBH,JX,CRLL,Z1,Z2,Z3,Z4,PNFSI,Z5,Z6,Z7,Z8,HERHT,ELE
 IV,ASP,HSLOP,HLAT,ZLATM,HLONG,ZLONGM
1573 FORMAT(1H1,42X,28HTREE AND PLOT INFORMATION ///5X,4HD3H=,F5.1,
 15X, 9HB.H. AGE=,I4,5X,12HCROWN CLASS=,F3.0,5X,26HHEIGHT TO FIRST L
 2IVE LIMB=,A3,1H.,A1,5X,21HHEIGHT TO LIVE CROWN=,A3,1H.,A1//5X,33HP
 3RELIMINARY NOBLE FIR SITE INDEX=,A3,16X,13HCLEAR LENGTH=,A3,1H.,A1
 4,5X,13HCROWN LENGTH=,A3,1H.,A1,5X,18HTOTAL TREE HEIGHT=,F6.1//
 55X,10HELEVATION=,F5.0,5X,7HASPECT=,F3.0,5X,6HSLOPE=,F4.0,1H%,5X,15
 6HLATITUDE NORTH=,F4.0,4H DEG,F6.1,23H MIN LONGITUDE WEST=,F4.0,
 74H DEG,F6.1,4H MIN//)
 WRITE(6,1103)ISP,IPL0T,ITREE,(HT(I),I=1,21),(DIA(J),J=1,21),(BT(K)
 1,K=1,21),(IAGE(KRB),KRB=1,21)
1103 FORMAT(54X,9HSPECIES =,I4/47X,9HPL0T NO.,I4,4X,9HTREE NO.,I3
 1//7X,8HST.HT ++,6X,21HDISTANCE FROM STUMP,32X,20HDISTANCE FROM
 2STUMP/7X,F6.1,1X,20F6.1,1X
 3 /1X,132(1H+)/1X,6HDIA OR,F6.1,1X,20F6.1/1X,6HBARK ,F6.2,1X,
 420F6.2/1X,132(1H+)/4H AGE,3X,I6,1X,20I6)

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```

1604 CONTINUE
 JDBH=DBH*10.+.5
 DO 41 IV=1,ISEC
 JH(IV)=HT(IV)*10.+.5
 JD(IV)=DIA(IV)*100.+.5
41 JB(IV)=BT(IV)*100.+.5
 KNC=1
 KDBH=DBH*10.+.5
 IF(ISC RD.GT.0)GO TO 49
 WRITE(7,1572)IHP,IHT,IHS,IHDBH,JX,IHC,IHSEC,IHAI,YCUT,GR_L,Z1,Z2,Z
13,Z4,Z5,Z6,Z7,Z8,ELEV,ASP,HSLOP,NLAT,NLONG,PNFSI,NERHT
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(JH(KV),KV=1,15)
1105 FORMAT(I3,I1,I3,2I4,2I2,I1,15I4)
 IF(ISEC.GT.15)GO TO 42
 GO TO 43
42 KNC=KNC+1
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(JH(KV),KV=16,30
1)
43 KNC=KNC+1
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(JD(KW),KW=1,15)
 IF(ISEC.GT.15) GO TO 44
 GO TO 45
44 KNC=KNC+1
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(JD(KW),KW=16,30
1)
45 KNC=KNC+1
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(JB(KX),KX=1,15)
 IF(ISEC.GT.15) GO TO 46
 GO TO 47
46 KNC=KNC+1
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(JB(KX),KX=16,30
1)
47 KNC=KNC+1
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(IAGE(KS),KS=1,
115)
 IF(ISEC.GT.15) GO TO 48
 GO TO 49
48 KNC=KNC+1
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(IAGE(KS),KS=16,
130)
49 IADI=IAGE(1)/XINCR
 LOV=IAGE(1)-(XINCR*IADI)
 IF(LOV.EQ.0)IADI=IADI-1
 IAD2=IADI
 DO 24 IPOJ=1,ICARD
 IHIST=YCUT-(IADI*XINCR)
 IADI=IADI-1
 IF(ISHNT.GT.0)GO TO 1605
 WRITE(6,1104)IHIST,(RESCL(IB,IPOJ),IB=1,21)
1104 FORMAT(I5,2X,F6.2,1X,20F6.2)
1605 CONTINUE
 KNC=KNC+1
 IF(KNC.GT.98)KNC=98
 IF(ISC RD.GT.0)GO TO 24
 WRITE(7,1105)IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(IRL(IG,IPOJ),IG
1=1,15)

```

```

 IF (ISEC.GT.15) GO TO 51
 GO TO 24
51 IF (IRL(16,IPOJ).GT.0) GO TO 52
 GO TO 24
52 KNC=KNC+1
 IF (KNC.GT.98) KNC=98
 WRITE(7,1105) IPLOT,ITREE,ISP,KDBH,IA,KNC,ISEC,IAI,(IRL(16,IPOJ),IG
1=16,30)
24 CONTINUE
 IF (ISEC.GT.21) GO TO 53
 GO TO 8787
53 CONTINUE
 IF (ISPNT.GT.0) GO TO 3787
 WRITE(6,1107) ISP,IPLOT,ITREE,(HT(I),I=22,30),(DIA(J),J=22,30),(BT(
1K),K=22,30),(IAGE(KRB),KRB=22,30)
1107 FORMAT(1H1,53X,9HSPECIES=,I4/47X,9HPLOT NO.,I4,4X,9HTREE NO.,I3
1,4X,9HCONTINUED//13X,21HDISTANCE FROM STUMP,32X,21HDISTANCE FRO
2M STUMP/13X,9F6.1/1X,67(1H+)/1X,6HDIA DB,6X,9F6.1/1X,64BARK ,6X
3,9F6.2/1X,67(1H+)/4H AGE,9X,9I6)
 DO 54 IU=1,ICAP
 IHIST=YYCUT-(IAD2*XINCR)
 IAD2=IAD2-I
 IF (RESCL(22,IU).EQ.0.0) GO TO 54
 WRITE(6,1108) IHIST,(RESCL(JU,IU),JU=22,30)
1108 FORMAT(15,8X,9F6.2)
54 CONTINUE
8787 CONTINUE
 IF (ISSPT.GT.0) GO TO 1609
 YINK=10.
 IF (IA1.EQ.3) YINK=5.0
 XINK=2.0
 IF (IAI.EQ.3) XINK=1.0
 CALL AXIS(0.0,0.0,YAXI,30,27.5,90.0,0.0,YINK,10.,-1)
 CALL AXIS(0.0,0.0,XAXI,-30,20.0,0.0,0.0,XINK,20.,-1)
 SPI=ISP
 TREEI=ITREE
 PLOTI=IPLOT
 SSTAGE=IAGE(1)
 CALL SYMBOL(5.0,27.0,.25,12HSTEM PROFILE,0.0,12)
 CALL SYMBOL(5.0,26.5,.25,4HPLOT,0.0,4)
 CALL NUMBER(6.25,26.5,.25,PLOTI,0.0,-1)
 CALL SYMBOL(5.0,26.0,.25,4HTREE,0.0,4)
 CALL NUMBER(6.25,26.0,.25,TREEI,0.0,-1)
 CALL SYMBOL(5.0,25.5,.25,7HSPECIES,0.0,7)
 CALL NUMBER(7.25,25.5,.25,SPI,0.0,-1)
 CALL SYMBOL(5.0,25.0,.25,3HAGE,0.0,3)
 CALL NUMBER(6.25,25.0,.25,SSTAGE,0.0,-1)
 CALL SYMBOL(5.0,24.5,.25,6HDBH AGE,0.0,6)
 CALL NUMBER(7.25,24.5,.25,XPAGE,0.0,-1)

```

```

C
C CALCULATE HEIGHT BETWEEN SECTIONS FOR STEM PROFILES
C AND PLOT STEM PROFILE
C
DO 445 IHER=1,80
DO 444 IREX=1,31
CHT(IREX)=HT(1)+HT(IREX)
IF(RESCL(1,IHER).EQ.0.0) GO TO 455
IF(IREX.EQ.1) CHT(1)=HT(1)
AXISH=CHT(IREX)/YINK
IF(RESCL(IREX,IHER).LE.0.0)447,448
447 DIFFA=IAGE(IREX-1)-IAGE(IREX)
DIFFH=CHT(IREX)-CHT(IREX-1)
ISA=IAGE(1)/XINCR
DA=IAGE(1)-(ISA*XINCR)
IF(DA.EQ.0.0)641,642
642 SA=DA+(IHER-1)*XINCR
GO TO 449
641 SA=(IHER)*XINCR
449 ANOM=SA-AGAS(IREX-1)
AXISH=((ANOM/DIFFA)*DIFFH)+CHT(IREX-1))/YINK
AXISR=0.0
CALL SYMBOL(AXISR,AXISH,.05,3,0.0,-2)
GO TO 445
448 IF(AXISH.GT.27.5) GO TO 455
AXISR=RESCL(IREX,IHER)/XINK
IF(AXISR.GT.20.0) GO TO 455
IF(IREX.EQ.1) 451,452
451 CALL SYMBOL(AXISR,AXISH,.05,3,0.0,-1)
GO TO 444
452 CALL SYMBOL(AXISR,AXISH,.05,3,0.0,-2)
444 CONTINUE
445 CONTINUE

C
C PLOT OUT HEIGHT OVER AGE GRAPHS
C
455 CONTINUE
CALL ADVANZ(44)
CALL PLOT(0.0,0.0,19)
1609 CONTINUE
IF(IHAPT.GT.0)GO TO 1
YINK=10.
IF(IAI.EQ.3)YINK=5.0
XINK=25.0
IF(IAI.EG.3)XINK=5.0
CALL AXIS(0.0,0.0,YAX2,30, 27.5,90.0,0.0,YINK,10.0,-1)
CALL AXIS(0.0,0.0,XAX2,-30,21.0, 0.0,0.0,XINK,10.0,-1)
CALL SYMBOL(5.0,26.5,.25,4HPLOT,0.0,4)
CALL NUMBER(6.25,26.5,.25,PLOTI,0.0,-1)
CALL SYMBOL(5.0,26.0,.25,4HTREE,0.0,4)
CALL NUMBER(6.25,26.0,.25,TREEI,0.0,-1)
CALL SYMBOL(5.0,25.5,.25,7HSPECIES,0.0,7)
CALL NUMBER(7.25,25.5,.25,SPI,0.0,-1)
CALL SYMPO(5.0,25.0,.25,3HAGE,0.0,3)
CALL NUMBER(6.25,25.0,.25,SSTAGE,0.0,-1)

```

```

CALL SYMBOL (5.0,24.5,.25,6HBH AGE,0.0,6)
CALL NUMBER (7.25,24.5,.25,XPAGE,0.0,-1)
DO 453 IREG=1,31
XP=AGAS(IREG)/XINK
YP=CHT(IREG)/YINK
IF (AGAS(IREG).GT.525) GO TO 456
IF (IAGE(IREG).LE.0.AND.HT(IREG).LE.0.0) GO TO 456
IF (XP.GT.21.0) GO TO 456
IF (YP.GT.28.0) GO TO 456
CALL SYMBOL(XP,YP,.05,3,0.0,-1)
453 CONTINUE
456 CALL ADVANZ(44)
CALL FLOT(0.0,0.0,19)
GO TO 1
9000 CONTINUE
CALL PLOT (22.0,0.0,-3)
CALL PLOT(0,0,999)
986 STOP
END

```





Herman, Francis R., Donald J. DeMars, and Robert F. Woollard

1975. Field and computer techniques for stem analysis of coniferous forest trees. USDA For. Serv. Res. Pap. PNW-194, 51 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Presents step-by-step instructions for stem analysis field and computer techniques which are adaptable to trees up to 800 years old. Stem profiles, height-age graphs, cards, and data lists are produced by the computer for any conifer for which growth information is to be analyzed.

Keywords: Stem analysis, age determination, ring measurement, data recording methods.

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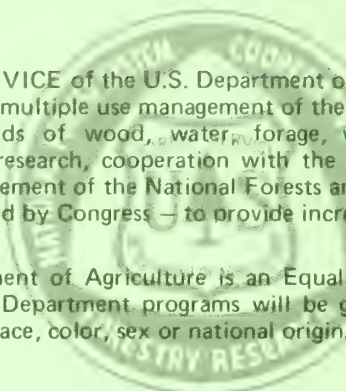
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Comparison of Western Spruce Budworm  
Populations and Damage on  
Grand Fir  
and  
Douglas-fir  
Trees



V.M. Carolin  
W.K. Coulter





# COMPARISON OF WESTERN SPRUCE BUDWORM POPULATIONS AND DAMAGE ON GRAND FIR AND DOUGLAS-FIR TREES

## Reference Abstract

Carolyn, V. M., and W. K. Coulter

1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Serv. Res. Pap. PNW-195, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Western spruce budworm populations and damage on grand fir and Douglas-fir were compared. Grand fir showed more damage than Douglas-fir in a given period of time. Egg populations on the two tree species were similar in the upper crown third, but higher on Douglas-fir in the middle and lower crown thirds. Larval density was similar. As larval populations increased, grand fir showed more defoliation than Douglas-fir.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, Douglas-fir, grand fir, defoliation damage.

## RESEARCH SUMMARY

### Research Paper PNW-195

1975

The increasing abundance of grand fir in stands of the mixed conifer type in eastern Oregon and Washington could intensify the hazard posed by the western spruce budworm. A preliminary study indicated that grand fir suffered serious damage and Douglas-fir minor damage after a 4-year period of visible infestation. Subsequent studies were based on paired-tree observations to clarify damage relationships between the western spruce budworm and grand fir, for comparison with Douglas-fir.

Damage was consistently higher on grand fir than on Douglas-fir in each study but was not the result of higher budworm populations. Egg populations on the two species were similar in the upper crown third, but Douglas-fir had significantly higher populations than grand fir in the lower crown third. Density of larvae per unit of new shoots was similar between the two tree species; number of larvae per twig lot usually differed.

With more intensive larval sampling, early damage on grand fir can probably be predicted with some confidence. These studies indicated that 10-tree cluster plots were a minimum basis for sampling to obtain sufficient data for regression analysis. Although percent defoliation of new growth is an index to the incidence of damage, particular attention should be paid to bud-killing and top-killing on grand fir.



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## INTRODUCTION

The western spruce budworm (*Choristoneura occidentalis* Freeman) is the most widely distributed and destructive forest defoliator in western North America (Carolin and Honing 1972). Its larvae mine needles, bore into vegetative buds and staminate flowers, then feed on the expanding new growth. They will feed on old foliage if the new growth is destroyed by feeding or frost. Effects on trees include needle loss, loss in radial and height increment, top-killing, and tree mortality. In the northern Rocky Mountains, larvae often destroy green cones.

In eastern Oregon and Washington, the budworm is especially damaging to grand fir (*Abies grandis* (Dougl.) Lindl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Forest practices have changed tree species composition in the east-side mixed conifer forests, and Edgerton (1973) considers these forests now to be dominated by grand fir. Increasing abundance of grand fir may lead to an intensification of the budworm problem. In studies at the end of a 12-year outbreak in northeast Oregon, Williams (1966, 1967) found that external damage symptoms indicated degrees of reduction in radial increment and that grand fir suffered heavier damage than Douglas-fir.

Budworm populations increase gradually, rather than explosively. Thus the intensity of early feeding damage should provide a basis for predicting economic growth losses more than a year before they occur. However, these predictions should be based on reactions of different tree species and their abundance.

Prediction is usually based on insect population levels and a convenient correlated indicator of damage. Some predictive capacity has been developed for the western budworm on Douglas-fir, and population levels are used to predict the degree of defoliation of new growth. To predict defoliation, a sequential plan has been developed for egg mass surveys in the central and southern Rocky Mountains (McKnight et al. 1970); and tables relating egg mass density and density of small larvae to categories of defoliation have been prepared for eastern Oregon (Carolin and Coulter 1972). In the absence of separate guidelines for grand fir and other associated species, there has been a tendency to apply the standards for Douglas-fir to these species.

During our budworm studies on Douglas-fir, as opportunity occurred, we attempted to compare populations and damage between grand fir and Douglas-fir by means of paired observations on the two species. At this time (1955-62), extensive control programs were in full swing and our choice of study areas was limited. When grand fir and Douglas-fir were intermixed, one usually predominated. More often the two species occurred in separate but adjacent stands. The number of comparisons was limited, but perhaps sufficient to identify differences in budworm damage and populations between the two species.

For purposes of evaluation surveys, the following questions are posed as a basis for interpreting data obtained.

1. Do adjacent grand fir and Douglas-fir trees show differences in damage early in the development of an outbreak?
2. Are differences in damage between the two tree species explained by differences in budworm density and distribution?
3. Can defoliation of new shoot growth on grand fir be reliably predicted from samples of feeding larvae?

## METHODS

A brief summary of individual studies, by objective, is shown below. Its purpose is to clarify the chronology of the different studies and the occasional conduct of different studies in the same locality in the same time period.

| <u>Studies</u>                                            | <u>Years</u> | <u>Locality</u>     |
|-----------------------------------------------------------|--------------|---------------------|
| Early tree damage (defoliation, top-killing, bud-killing) | 1955         | North Powder, Oreg. |
|                                                           | 1956-59      | Baker, Oreg.        |
|                                                           | 1958-59      | Halfway, Oreg.      |
| Budworm density and distribution:                         |              |                     |
| Egg masses                                                | 1958-59      | Halfway, Oreg.      |
|                                                           | 1960-61      | Goldendale, Wash.   |
| Larvae                                                    | 1956-57      | Baker, Oreg.        |
|                                                           | 1959         | Halfway, Oreg.      |
|                                                           | 1962         | Goldendale, Wash.   |
| Correlation of larval density and defoliation             | 1959         | Halfway, Oreg.      |
|                                                           | 1960-61      | Goldendale, Wash.   |

### EARLY TREE DAMAGE

Damage criteria included percent defoliation of current needle growth, percent defoliation of all needle growth, presence or absence of top-killing, and incidence of bud-killing. Defoliation estimates were made for each crown third by observers using fieldglasses. A single estimate for the tree was obtained by weighting crown third estimates as follows: upper--1, middle--3, and lower--5 (Carolin and Coulter 1972). Killed tops were identified by dead wood, color of the leader, absence of buds and needles, and development of lateral shoots into multiple leaders. Bud-killing was arbitrarily classified as low, moderate, or high. The "low" category was applied when 15 percent or less of the buds were killed; "high" was defined as more than 50 percent.

A preliminary study compared both current and cumulative tree damage on grand fir and Douglas-fir after 4 years of generally visible feeding at a plot near North Powder, Oregon. At the beginning of an infestation, a plot was established,

consisting of 10 subplots 5 chains apart on a compass line; each subplot was a cluster of three trees. During 1951 through 1954, egg and larval populations were sampled and broad estimates of current defoliation made each year. Final damage estimates were obtained in early spring of 1955. Although estimates were made at nine subplots, direct comparisons between codominants and intermediates of the two species were possible at only three subplots. At these subplots, grand fir was twice as abundant as Douglas-fir. An adjacent subplot had been logged, and in six other subplots Douglas-fir greatly predominated. In the summer of 1955, the plot and general area were sprayed with DDT in an extensive budworm control project.

Starting in 1956, a second study on cumulative damage was based on five pairs of lightly defoliated intermediate grand fir and Douglas-fir trees near Baker, Oregon, in a gulch next to a long-term Douglas-fir plot. Pairs were located on a line, with each pair 1 chain apart. In 1956 and 1957, trees were sampled for density of full-grown larvae; but no fieldglass estimates of defoliation were made. In 1958, plot trees accidentally received a light coverage of DDT spray. Estimates of top-kill and bud-kill were made in both 1958 and 1959. Comparisons between the two species were on an empirical basis.

In a third study, damage was compared on 10 numbered pairs of codominant trees in 1958 and 1959 at a cluster plot near Halfway, Oregon. Light defoliation was first observed during a ground reconnaissance in 1956. In 1958, defoliation estimates were made on 5 pairs by one observer and in 1959 on all 10 pairs by two observers. Condition of tops was examined in both years. In 1958, incidence of bud-killing was classified in a general way; and in 1959, sample twigs were examined and percent buds killed was recorded for each tree. Analysis of variance was used to test for significant differences in defoliation and bud-kill between species.

## BUDWORM DENSITY AND DISTRIBUTION

*Egg masses.* --Densities of egg masses on five pairs of trees were compared at the previously mentioned cluster plot near Halfway, Oregon, in 1958 and 1959. This was a light infestation; hence comparisons were made only at midcrown. Two whole branches from each of five trees of each species were cut and examined and new egg masses expressed both on a branch basis and per thousand square inches of foliated branch area. Differences in density, using the two units, were tested for tree species and years by analysis of variance and the t-test. This study was terminated at the end of 1959 because of a general decline in infestations in northeast Oregon.

The next comparisons were made in 1960 and 1961 in a rapidly arising infestation near Goldendale, in the eastern Washington Cascades. In both years, density of egg masses by crown height on grand fir alone was estimated by sampling low, middle, and upper crown thirds on the same 5 trees in a 10-tree cluster plot. In the second year, at a second plot, similar observations were made on five pairs of grand fir and Douglas-fir. Sampling involved removing and counting

new egg masses on two whole branches in the upper third, two longitudinal half-branches in the middle third, and one whole branch in the lower third. The single branch from the lower third contained about the same amount of foliage area as the two middle third branches. Number of egg masses was expressed both on a branch basis and per thousand square inches of foliage. For grand fir alone, analysis of variance was to determine significant differences in egg mass density between crown levels. For the grand fir-Douglas-fir comparisons, analysis of variance was to determine significant differences between crown levels and between tree species. Separate analyses were run for the two expressions of egg mass density.

*Larvae.* --Densities of full-grown larvae were compared in both 1956 and 1957 on the five pairs of grand fir and Douglas-fir used in the damage study at the Baker plot. Each tree was sampled by cutting four 15-inch twigs at random from the lower crown half, using a pole-pruner. Both spruce budworm and new shoots on each twig sampled were counted. Larval density was expressed as number of larvae per four 15-inch twigs and per 100 buds or new shoots on these twigs. Differences in density between tree species were tested by analysis of variance.

Densities of budworm larvae in opening shoots were compared on paired codominants of the two species at the Halfway plot in 1959 and at the Goldendale plot in 1962. In the 1959 and 1962 studies, 10 and 5 pairs of trees, respectively, were used. Populations were low to medium at Halfway and high at Goldendale. Sampling techniques were as described for the Baker study. However, at Halfway six twigs and at Goldendale four twigs were a twig lot.

## CORRELATION BETWEEN LARVAL DENSITY AND DEFOLIATION

This effort was aimed principally at grand fir, because the relationship between larval density and percent defoliation of current growth had been established for Douglas-fir in eastern Oregon. However, comparisons of the larvae-damage relationship were attempted between species at the same or adjacent plots where possible.

At the Halfway plot in 1959, 10 trees of each species were sampled for bud-feeding larvae and defoliation estimates (already noted) made in fall. Regression analyses were run between percent defoliation of current growth and number of larvae, and also larvae per 100 shoots. Similar efforts were made in 10-tree cluster plots in the Goldendale area, but these were single-species plots. They consisted of: one grand fir plot sampled in both 1960 and 1961; one Douglas-fir plot, less than one-half mile away, in both 1960 and 1961; and a second grand fir plot sampled only in 1961. Four 15-inch twigs constituted the larval sample, and number of new shoots was counted on each twig. Whereas populations at Halfway drastically declined the following year, those at Goldendale were in a rapidly increasing infestation which was sprayed in 1962.



## RESULTS

### EARLY TREE DAMAGE

In the preliminary study at the North Powder plot, grand fir trees showed more damage than adjacent Douglas-fir trees in the same crown class (table 1). Grand fir had higher defoliation of 1954 needle growth and all needle growth than Douglas-fir, except for intermediates at plots 2 and 8 where defoliation was similar. Grand fir had a high incidence of bud-killing; with one exception, Douglas-fir had low bud-kill. Of 6 codominant grand fir, 3 had dead tops; 10 of 12 intermediate grand firs were top-killed. Douglas-fir trees all had living tops. In previous studies, generalized estimates of current defoliation were as follows: 1951--light; 1952--light; 1953--light to moderate; and 1954--heavy. Thus, after 2 years of generally visible light defoliation followed by 2 years of higher defoliation, grand fir showed serious crown damage and Douglas-fir minor crown damage.

In the paired five-tree study at the Baker plot, total defoliation was not estimated; but other criteria showed that grand fir trees were damaged more than Douglas-fir. In 1958, three grand firs had tops defoliated but alive, one had its top killed with two new leaders developing, and one had a killed top with no recovery evident. In 1959, a year after the DDT spraying, four of the grand fir trees showed leader growth; the fifth showed no recovery. Bud-kill on the fifth tree, particularly in the middle and upper crown thirds, was high. In contrast, all five Douglas-fir trees had living leaders and virtually no bud-kill. In addition to harboring a budworm infestation, the Douglas-fir trees had an infection of a needle-blight fungus (*Rhabdocline* sp.) which caused conspicuous defoliation in 1959.

At the Halfway plot, average defoliation of current growth was twice as high on grand fir as on Douglas-fir (table 2). The differences were significant<sup>1/</sup> in 1958 and highly significant in 1959. Bud-kill in 1958 was inconsequential on both species; in 1959, it averaged higher on grand fir than on Douglas-fir (table 2); but the difference was not significant. No top-killing occurred in this light infestation. Tops of both species had light defoliation (less than 25 percent) in 1958; grand fir tops were heavily defoliated in 1959.

### BUDWORM DENSITY AND DISTRIBUTION

*Egg masses.* --In the light infestation at Halfway, egg mass density at mid-crown was higher on Douglas-fir than on grand fir (table 3); but in neither year was the difference significant. Relative variation was typically high for these low populations, and adjustment of egg mass counts to a common foliated branch area basis tended to raise egg mass densities on grand fir because of its smaller branch size. At any rate, there is no evidence that the higher defoliation on grand fir recorded for 2 years at this plot was due to higher egg mass density on this species.

<sup>1/</sup> In this paper,  $p < 0.05$  is significant, and  $p < 0.01$  is highly significant.



Table 1.--Damage on grouped Douglas-fir and grand fir trees after 4 years of visible feeding,  
North Powder, Oregon, spring of 1955

| Subplot<br>and<br>tree species | Dominants and codominants |                   |               |                    | Intermediates      |                   |               |                                   |
|--------------------------------|---------------------------|-------------------|---------------|--------------------|--------------------|-------------------|---------------|-----------------------------------|
|                                | Number<br>of trees        | Defoliation       |               | Other damage       | Number<br>of trees | Defoliation       |               | Other damage                      |
|                                |                           | 1954<br>growth    | All<br>growth |                    |                    | 1954<br>growth    | All<br>growth |                                   |
|                                |                           | -Average percent- |               | --Incidence--      |                    | -Average percent- |               | --Incidence--                     |
| 1: Douglas-fir<br>Grand fir    | 3<br>0                    | 31<br>--          | 5<br>--       | Low<br>--          | 5<br>0             | 18<br>--          | 5<br>--       | Low<br>--                         |
| 2: Douglas-fir<br>Grand fir    | 3<br>0                    | 26<br>--          | 5<br>--       | Low<br>--          | 5<br>2             | 23<br>16          | 5<br>5        | Low<br>Low                        |
| 3: Douglas-fir<br>Grand fir    | 3<br>0                    | 33<br>--          | 5<br>--       | Low<br>--          | 5<br>0             | 10<br>--          | 5<br>--       | Low<br>--                         |
| 4: Douglas-fir<br>Grand fir    | 2<br>0                    | 16<br>--          | 5<br>--       | Low<br>--          | 5<br>0             | 12<br>--          | 5<br>--       | Low<br>--                         |
| 5: Douglas-fir<br>Grand fir    | 3<br>0                    | 22<br>--          | 10<br>--      | Low<br>--          | 5<br>0             | 13<br>--          | 5<br>--       | Low<br>--                         |
| 6: Douglas-fir<br>Grand fir    | 2<br>3                    | 61<br>94          | 13<br>21      | Low<br>Low to high | 0<br>5             | --<br>--          | --<br>24      | --<br>High                        |
| 7: Trees logged                | --                        | --                | --            | --                 | --                 | --                | --            | --                                |
| 8: Douglas-fir<br>Grand fir    | 0<br>3                    | --<br>97          | --<br>29      | --<br>2/High       | 2<br>5             | 98<br>99          | 39<br>33      | Low to high<br>High <sup>2/</sup> |
| 9: Douglas-fir<br>Grand fir    | 0<br>0                    | --<br>--          | --<br>--      | --<br>--           | 4<br>0             | 60<br>--          | 8<br>--       | Low<br>--                         |
| 10: Douglas-fir<br>Grand fir   | 2<br>0                    | 57<br>--          | 6<br>--       | Low<br>--          | 5<br>0             | 23<br>--          | 5<br>--       | Low<br>--                         |

<sup>1/</sup> Low indicates 15 percent or less, and high 50 percent or more, of the buds killed.

<sup>2/</sup> Nearly complete bud-kill on these trees.

Table 2.--Damage on paired Douglas-fir and grand fir trees during 2 early years of visible feeding, Halfway, Oregon, 1958-59

| Year and tree number       | Current defoliation |           | Bud-kill    |           |
|----------------------------|---------------------|-----------|-------------|-----------|
|                            | Douglas-fir         | Grand fir | Douglas-fir | Grand fir |
| ----- <u>Percent</u> ----- |                     |           |             |           |
| 1958:                      |                     |           |             |           |
| 2                          | 10                  | 44        | <10         | <10       |
| 4                          | 16                  | 69        | <10         | <10       |
| 6                          | 9                   | 42        | <10         | <10       |
| 8                          | 23                  | 24        | <10         | <10       |
| 10                         | 23                  | 35        | <10         | <10       |
| Average                    | 16.2                | 42.8      |             |           |
| 1959:                      |                     |           |             |           |
| 1                          | 29                  | 62        | 9           | 21        |
| 2                          | 8                   | 57        | 5           | 36        |
| 3                          | 20                  | 37        | 12          | 16        |
| 4                          | 17                  | 43        | 11          | 9         |
| 5                          | 20                  | 31        | 13          | 19        |
| 6                          | 9                   | 62        | 14          | 17        |
| 7                          | 15                  | 43        | 10          | 32        |
| 8                          | 34                  | 40        | 19          | 12        |
| 9                          | 18                  | 25        | 5           | 10        |
| 10                         | 27                  | 27        | 5           | 8         |
| Average                    | 19.7                | 42.7      | 10.3        | 18.0      |

Table 3.--Egg mass densities on two branches at midcrown on paired Douglas-fir and grand fir trees in a light infestation near Halfway, Oregon, 1958-59

| Year and tree number        | Douglas-fir             |               | Grand fir               |               |
|-----------------------------|-------------------------|---------------|-------------------------|---------------|
|                             | Foliage area            | Egg masses    | Foliage area            | Egg masses    |
|                             | <u>M in<sup>2</sup></u> | <u>Number</u> | <u>M in<sup>2</sup></u> | <u>Number</u> |
| 1958:                       |                         |               |                         |               |
| 2                           | 4.472                   | 5             | 3.180                   | 1             |
| 4                           | 3.780                   | 2             | 3.376                   | 10            |
| 6                           | 3.985                   | 2             | 2.344                   | 2             |
| 8                           | 4.783                   | 2             | 2.268                   | 0             |
| 10                          | 3.700                   | 19            | 1.241                   | 2             |
| Total                       | 20.720                  | 30            | 12.409                  | 15            |
| Column mean                 | --                      | 6.0           | --                      | 3.0           |
| Adjusted mean <sup>1/</sup> | --                      | 5.93          | --                      | 3.07          |
| 1959:                       |                         |               |                         |               |
| 2                           | 4.634                   | 8             | 1.180                   | 0             |
| 4                           | 2.526                   | 1             | 3.507                   | 1             |
| 6                           | 2.990                   | 3             | 2.516                   | 1             |
| 8                           | 3.026                   | 4             | 1.248                   | 2             |
| 10                          | 2.733                   | 6             | 1.667                   | 0             |
| Total                       | 15.909                  | 22            | 10.118                  | 4             |
| Column mean                 | --                      | 4.4           | --                      | 0.8           |
| Adjusted mean <sup>1/</sup> | --                      | 3.75          | --                      | 1.45          |

<sup>1/</sup> Adjusted to average foliated branch area for all tree samples.

In the heavy infestation in 1961 at Goldendale, where interspecies comparisons were made at three crown heights, significantly higher numbers of egg masses per branch were found in the lower and middle crown thirds of Douglas-fir trees, as compared with grand fir. Egg masses per thousand square inches are significantly higher in the lower third of Douglas-fir, but differences were not significant between the two species at the middle and upper thirds. Without the covariance correction for branch size, egg mass density in the middle third, as well as the lower third, becomes significantly higher on Douglas-fir. Simplified, the results show similar egg mass densities in the upper crown of the two tree species and dissimilar densities in the lower crown; egg masses were more uniformly distributed on the Douglas-fir trees (table 4).

Table 4.--Vertical distribution of egg masses on sample branches from paired Douglas-fir and grand fir trees near Goldendale, Washington, 1961

| Tree number                 | Douglas-fir          |            |                       |            |                      |            | Grand fir            |            |                       |            |                      |            |
|-----------------------------|----------------------|------------|-----------------------|------------|----------------------|------------|----------------------|------------|-----------------------|------------|----------------------|------------|
|                             | Lower third of crown |            | Middle third of crown |            | Upper third of crown |            | Lower third of crown |            | Middle third of crown |            | Upper third of crown |            |
|                             | Foliage area         | Egg masses | Foliage area          | Egg masses | Foliage area         | Egg masses | Foliage area         | Egg masses | Foliage area          | Egg masses | Foliage area         | Egg masses |
|                             | M in <sup>2</sup>    | Number     | M in <sup>2</sup>     | Number     | M in <sup>2</sup>    | Number     | M in <sup>2</sup>    | Number     | M in <sup>2</sup>     | Number     | M in <sup>2</sup>    | Number     |
| 1                           | 2.614                | 39         | 1.625                 | 34         | 1.710                | 107        | 2.660                | 2          | 2.040                 | 43         | 1.556                | 74         |
| 2                           | 4.510                | 114        | 4.026                 | 196        | 3.443                | 180        | 1.938                | 2          | 2.331                 | 32         | 1.127                | 31         |
| 3                           | 4.301                | 129        | 4.169                 | 106        | 1.606                | 60         | 5.040                | 46         | 2.278                 | 59         | 1.822                | 67         |
| 4                           | 3.120                | 110        | 2.822                 | 167        | 1.903                | 123        | 2.728                | 39         | 3.107                 | 73         | 1.834                | 105        |
| 5                           | 2.747                | 41         | 2.137                 | 101        | 2.506                | 82         | 3.397                | 16         | 2.400                 | 43         | 1.611                | 62         |
| Total                       | 17.292               | 433        | 14.779                | 604        | 11.168               | 552        | 15.763               | 105        | 12.156                | 250        | 7.950                | 339        |
| Column mean                 | --                   | 86.60      | --                    | 120.80     | --                   | 110.40     | --                   | 21.00      | --                    | 50.00      | --                   | 67.80      |
| Adjusted mean <sup>1/</sup> | --                   | 83.07      | --                    | 111.31     | --                   | 94.42      | --                   | 24.53      | --                    | 59.49      | --                   | 83.78      |

<sup>1/</sup> Adjusted to average foliated branch area for all tree samples.

The 2-year study in a grand fir plot at Goldendale confirmed the egg mass distribution pattern for grand fir found in the paired species test. In both years, number of egg masses per branch was lowest in the lower crown third and generally similar in the middle and upper thirds (table 5). Numbers of egg masses in the lower third were significantly different in 1960 but not in 1961. Egg masses per thousand square inches of foliage were very low in the lower third but increased progressively up the tree. In both years, densities in the lower third were significantly less than in the middle and upper crown thirds. Thus there is substantial evidence that the egg deposition pattern on grand fir differs from that on Douglas-fir reported by Carolin and Coulter (1972).

Table 5.--*Vertical distribution of egg masses on sample branches from grand fir trees near Goldendale, Washington, 1960-61*

| Year and tree number        | Lower third of crown    |               | Middle third of crown   |                  | Upper third of crown    |               |
|-----------------------------|-------------------------|---------------|-------------------------|------------------|-------------------------|---------------|
|                             | Foliage area            | Egg masses    | Foliage area            | Egg masses       | Foliage area            | Egg masses    |
|                             | <u>M in<sup>2</sup></u> | <u>Number</u> | <u>M in<sup>2</sup></u> | <u>Number</u>    | <u>M in<sup>2</sup></u> | <u>Number</u> |
| 1960:                       |                         |               |                         |                  |                         |               |
| 1                           | 5.525                   | 3             | 7.474 <sup>1/</sup>     | 15 <sup>1/</sup> | 3.721                   | 13            |
| 2                           | 3.150                   | 1             | 2.223                   | 4                | 1.707                   | 10            |
| 5                           | 1.888                   | 0             | 2.048                   | 5                | 1.926                   | 7             |
| 6                           | 2.492                   | 4             | 1.364                   | 5                | 1.011                   | 10            |
| 8                           | 2.822                   | 1             | 1.717                   | 7                | 1.285                   | 10            |
| Total                       | 15.877                  | 9             | 14.826                  | 36               | 9.650                   | 50            |
| Column mean                 | --                      | 1.80          | --                      | 7.20             | --                      | 10.00         |
| Adjusted mean <sup>2/</sup> | --                      | 1.13          | --                      | 6.82             | --                      | 11.05         |
| 1961:                       |                         |               |                         |                  |                         |               |
| 1                           | 2.268                   | 5             | 2.286                   | 6                | 3.993                   | 57            |
| 2                           | 3.867                   | 0             | 2.587                   | 15               | 5.712                   | 26            |
| 5                           | 4.128                   | 2             | 1.927                   | 7                | 1.760                   | 18            |
| 6                           | 2.016                   | 11            | 1.252                   | 46               | 1.026                   | 36            |
| 8                           | 2.600                   | 6             | 3.146                   | 47               | 1.362                   | 28            |
| Total                       | 14.879                  | 24            | 11.198                  | 121              | 13.853                  | 165           |
| Column mean                 | --                      | 4.80          | --                      | 24.20            | --                      | 33.00         |
| Adjusted mean <sup>2/</sup> | --                      | 4.63          | --                      | 24.43            | --                      | 32.94         |

<sup>1/</sup> Two whole branches, rather than two half-branches, were examined.

<sup>2/</sup> Adjusted to average foliated branch area for all tree samples.



*Larvae.* -- Comparisons in 1956 and 1957 at the Baker plot showed that average number of larvae per twig lot could differ considerably between species but that number per 100 shoots would be similar (table 6). In 1956, there was no significant difference between species in number either per twig lot or per 100 shoots. Average number of shoots per twig was generally similar: 43.6 on grand fir and 38.1 on Douglas-fir. In 1957 there was a significant difference in number of larvae per twig lot, with 31.4 for grand fir and 13.2 for Douglas-fir, but no significant difference in larvae per 100 shoots, with 13.3 for grand fir and 12.9 for Douglas-fir. Differences in numbers of shoots per twig between species, about 59 for grand fir and 28 for Douglas-fir, appeared to be a compensating factor in the 1957 sampling. However, because these comparisons were of full-grown larvae, the possibility of an artifact based on redistribution of the growing larvae was recognized. Subsequent studies were thus directed to larvae in opening buds.

Table 6.--Numbers and density of full-grown larvae on paired Douglas-fir and grand fir trees, Baker, Oregon, 1956-57

| Year and<br>tree number                             | Douglas-fir |                | Grand fir  |                |
|-----------------------------------------------------|-------------|----------------|------------|----------------|
|                                                     | On 4 twigs  | Per 100 shoots | On 4 twigs | Per 100 shoots |
| - - - - - <u>Number of spruce budworm</u> - - - - - |             |                |            |                |
| 1956:                                               |             |                |            |                |
| 1                                                   | 25          | 19.5           | 21         | 20.2           |
| 2                                                   | 31          | 18.0           | 27         | 11.3           |
| 3                                                   | 10          | 17.9           | 9          | 7.8            |
| 4                                                   | 20          | 10.6           | 8          | 6.3            |
| 5                                                   | 22          | 10.1           | 38         | 13.2           |
| Average                                             | 21.6        | 15.22          | 20.6       | 11.76          |
| 1957:                                               |             |                |            |                |
| 1                                                   | 13          | 17.1           | 32         | 16.9           |
| 2                                                   | 29          | 25.0           | 35         | 14.2           |
| 3                                                   | 8           | 10.7           | 47         | 17.9           |
| 4                                                   | 8           | 7.8            | 17         | 8.7            |
| 5                                                   | 8           | 4.1            | 26         | 8.8            |
| Average                                             | 13.2        | 12.94          | 31.4       | 13.30          |

At the Halfway plot, number of bud-feeding larvae per twig lot (six 15-inch twigs) was significantly higher on grand fir than on Douglas-fir, with means of 50.1 and 18.9, respectively. However, number per 100 shoots was not significantly different, with means of 18.5 for grand fir and 15.2 for Douglas-fir (table 7). There were more new shoots per 15-inch twig on grand fir (mean of 45.7) than on Douglas-fir (mean of 19.5).

Table 7.--Numbers and density of larvae in opening buds on paired Douglas-fir and grand fir trees, Halfway, Oregon, 1959

| Tree number                          | Douglas-fir |                | Grand fir  |                |
|--------------------------------------|-------------|----------------|------------|----------------|
|                                      | On 6 twigs  | Per 100 shoots | On 6 twigs | Per 100 shoots |
| - - - - - Number of larvae - - - - - |             |                |            |                |
| 1                                    | 39          | 22.9           | 36         | 20.4           |
| 2                                    | 26          | 29.2           | 70         | 25.3           |
| 3                                    | 5           | 4.5            | 54         | 14.8           |
| 4                                    | 8           | 5.6            | 76         | 19.4           |
| 5                                    | 15          | 16.0           | 42         | 16.6           |
| 6                                    | 1           | 1.9            | 38         | 12.8           |
| 7                                    | 11          | 12.4           | 35         | 18.9           |
| 8                                    | 63          | 47.0           | 41         | 17.3           |
| 9                                    | 4           | 5.3            | 75         | 27.7           |
| 10                                   | 17          | 7.4            | 34         | 11.6           |
| Average                              | 18.9        | 15.22          | 50.1       | 18.48          |

At the 1962 Goldendale plot, number of bud-feeding larvae per twig lot (four 15-inch twigs) was much higher on grand fir, with a mean of 127.2, than on Douglas-fir, with a mean of 69.8, but the difference was not statistically significant. Number of larvae per 100 shoots was not significantly different; means were 53.10 for grand fir and 42.08 for Douglas-fir (table 8). On both tree species, 15-inch twigs were heavily budded, averaging 62.6 new shoots per twig on grand fir and 42.3 on Douglas-fir. Thus, in this high population plot, as also found in the low to medium population plots at Baker and Halfway, densities of larvae in relation to number of buds were essentially similar for the two tree species.

## CORRELATION BETWEEN LARVAL DENSITY AND DEFOLIATION

In four cases, significant correlations were obtained between an expression of density of small larvae and percent defoliation of current growth. Two cases were at Douglas-fir plots and two at grand fir plots. Two further correlations, based on larval density in buds, were obtained at Douglas-fir plots by rejecting a single observation considered abnormal because of too few buds in the sample.

Table 8.--Numbers and density of larvae in opening buds on paired Douglas-fir and grand fir trees, Goldendale, Washington, 1962

| Tree number                          | Douglas-fir |                | Grand fir  |                |
|--------------------------------------|-------------|----------------|------------|----------------|
|                                      | On 4 twigs  | Per 100 shoots | On 4 twigs | Per 100 shoots |
| - - - - - Number of larvae - - - - - |             |                |            |                |
| 1                                    | 42          | 46.2           | 136        | 81.4           |
| 2                                    | 89          | 42.6           | 86         | 46.5           |
| 3                                    | 59          | 24.7           | 203        | 60.2           |
| 4                                    | 120         | 65.2           | 110        | 46.6           |
| 5                                    | 39          | 31.7           | 101        | 30.8           |
| Total                                | 349         | 210.4          | 636        | 265.5          |
| Average                              | 69.8        | 42.08          | 127.2      | 53.10          |

*Larvae per twig lot.*--Larval density and percent defoliation were significantly correlated on Douglas-fir at Halfway in 1959 ( $r = 0.69$ ), at Goldendale in 1961 ( $r = 0.635$ ), and also on grand fir at Goldendale in 1960 ( $r = 0.71$ ). Relationships were linear in each case. Larval counts were transposed from a 4- and 6-twig basis to a 100-twig basis and damage curves compared (fig. 1). Regression lines for the two Douglas-fir plots have an identical slope, but the regression line for Goldendale is at a higher level than that for Halfway. In contrast, the line for the grand fir plot at Goldendale (1960) has a steeper slope and, as populations increase, more defoliation is shown for a given larval density than on Douglas-fir.

When twig lot is used as the independent variable, number of new shoots per twig can affect the damage relationship. However, average number of shoots per twig was 36 at this grand fir plot and 24.5 and 20 at the Douglas-fir plots at Goldendale and Halfway, respectively. Grand fir suffered more damage, even though there were more, rather than less, shoots per twig.

*Larvae per unit number of buds.*--In the initial analyses, larval density per 100 buds and percent defoliation were significantly correlated ( $r = 0.775$ ) only on grand fir at Goldendale in 1960. Two further correlations ( $r = 0.70$ ,  $r = 0.78$ ) were obtained at Douglas-fir plots by rejecting single trees. Tree 2 at Halfway was rejected because of the scarcity of branches in the lower crown third and tree 1 at Goldendale in 1961 because so few buds were on the twig samples.

Comparison of regression lines shows grand fir again to have a steeper slope and higher defoliation with increasing populations than Douglas-fir (fig. 2), the same as when larvae per twig lot was the independent variable. Regression

lines for Douglas-fir, based on larvae per 100 buds, are not directly comparable with predictive equations already presented (Carolin and Coulter 1972) because of the lack of trees having defoliation exceeding 50 percent. For this same reason, the regression line for grand fir will require validation before it can be used for prediction.

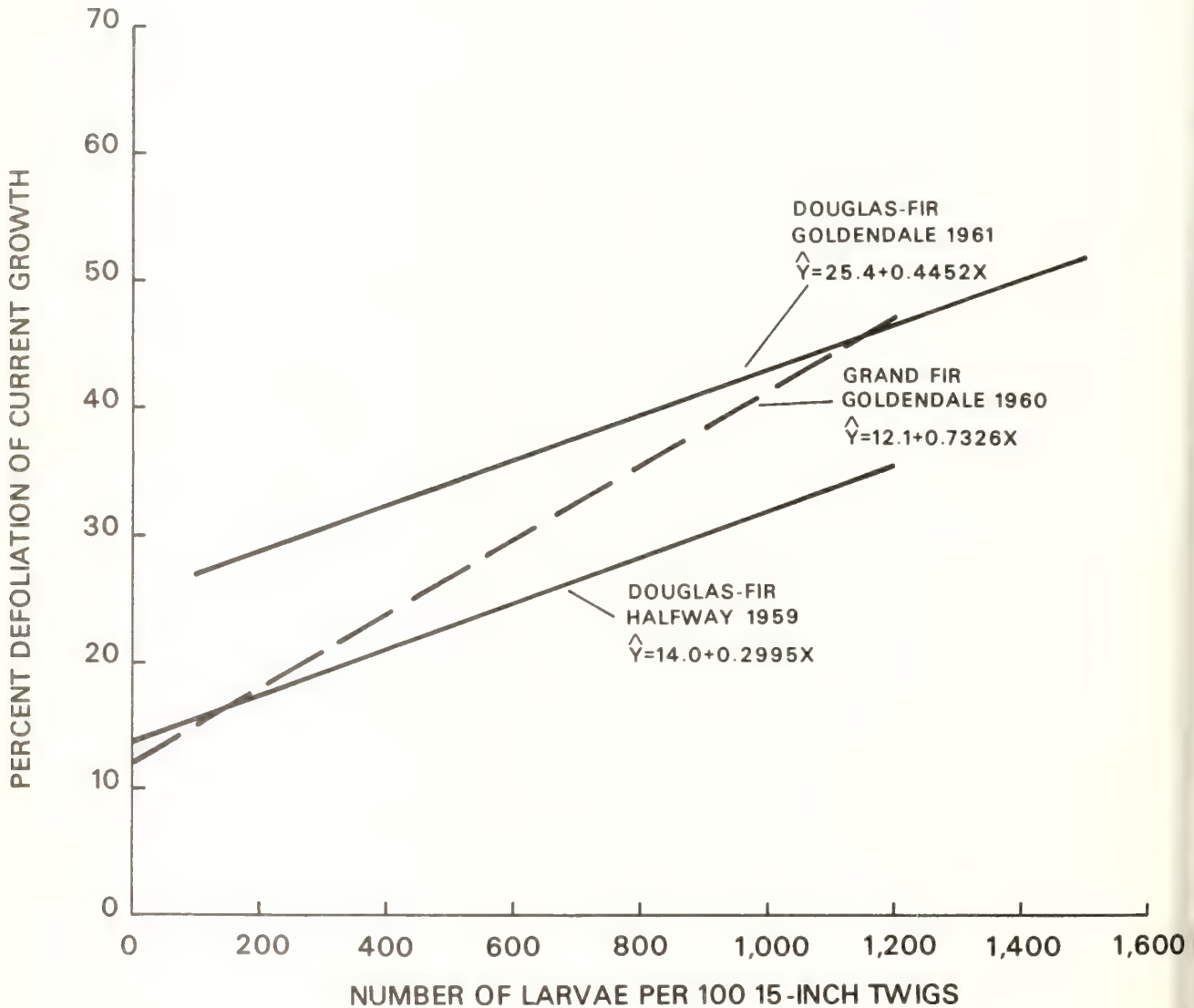


Figure 1.--Linear regression of defoliation of current growth on larval density on twig samples.

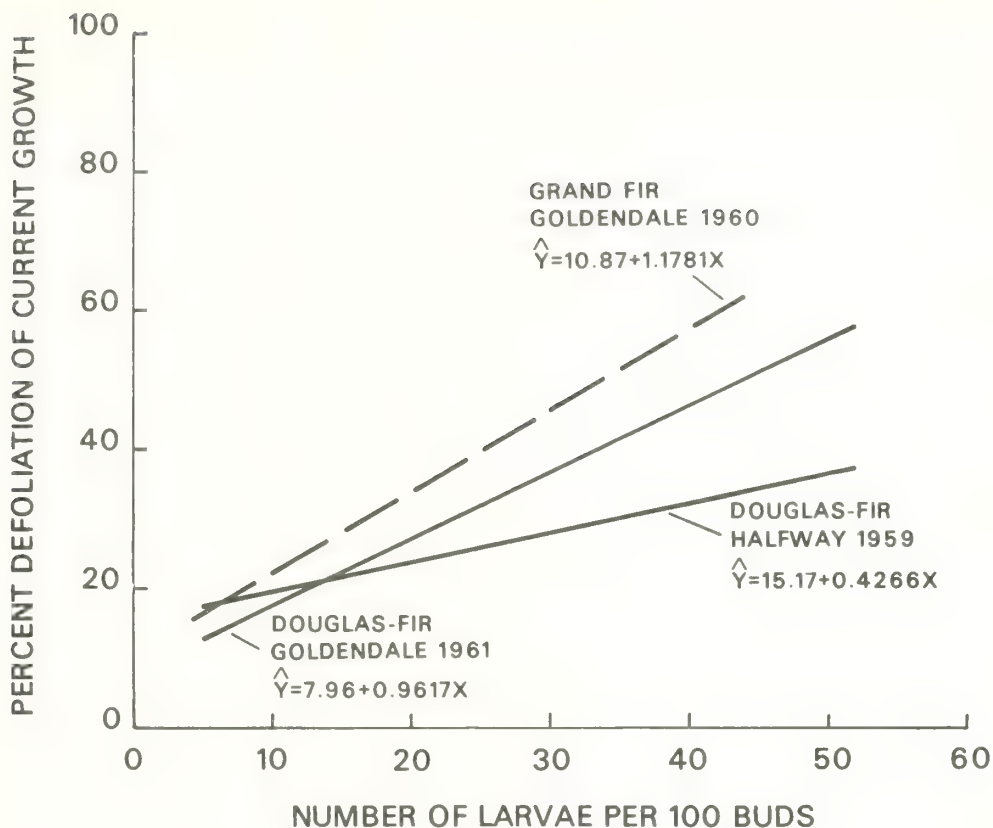


Figure 2.--Linear regression of defoliation of current growth on larval density in buds.

## CONCLUSIONS

In answer to the three questions posed at the beginning of this report, the following conclusions are reached:

1. Adjacent grand fir and Douglas-fir trees show strong differences in budworm-caused damage early in an outbreak. Grand fir suffers serious bud damage and incipient top-killing within 4 years, 2 of which involve medium or high populations. Douglas-fir, in the same period, shows only minor damage.
2. A higher incidence of damage on grand fir, as compared with Douglas-fir, cannot be attributed to higher egg or larval populations on grand fir. Egg populations on grand fir and Douglas-fir are similar in the upper crown third, the critical part of the tree so far as damage is concerned; they are dissimilar in the lower two-thirds of the crown, with Douglas-fir having significantly higher populations than grand fir in the lower third. Density of larvae per unit of new shoots is similar between the two tree species; number of larvae per twig lot usually differs.



3. With more intensive sampling, larval sampling can probably be used as a basis for predicting early damage on grand fir; a 10-tree sample at a cluster plot is minimal for predicting defoliation on grand fir, as well as Douglas-fir. After grand fir has suffered serious bud damage, subsequent predictions of defoliation alone are meaningless and special attention should be paid to the incidence of bud-killing and top-killing.

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1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Serv. Res. Pap. PNW-195, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Western spruce budworm populations and damage on grand fir and Douglas-fir were compared. Grand fir showed more damage than Douglas-fir in a given period of time. Egg populations on the two tree species were similar in the upper crown third, but higher on Douglas-fir in the middle and lower crown thirds. Larval density was similar. As larval populations increased, grand fir showed more defoliation than Douglas-fir.

**Keywords:** Western spruce budworm, *Choristoneura occidentalis*, Douglas-fir, grand fir, defoliation damage.

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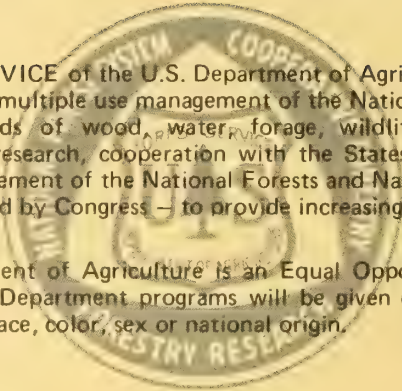
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# **DEFECT ESTIMATION for WHITE FIR in the FREMONT NATIONAL FOREST**

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# DEFECT ESTIMATION FOR WHITE FIR IN THE FREMONT NATIONAL FOREST

## Reference Abstract

Aho, Paul E., and Philip Simonski.

1975. Defect estimation for white fir in the Fremont National Forest. USDA For. Serv. Res. Pap. PNW-196, 9 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Two methods for estimating defect in standing white firs are presented for use by timber cruisers in the Fremont National Forest. Defect percentages of gross merchantable cubic-foot and Scribner board-foot volumes are tabulated by d.b.h. only and also by age and d.b.h. Constant defect percentages must then be added for various indicators. The multiple regression equations used to derive the tables are provided. Average length deductions below and above major indicators plus flat percentage factors for hidden defect are presented.

Keywords: White fir, *Abies concolor*, Indian paint fungus, *Echinodontium tinctorium*, defect deduction(-merchantable volume).

## Research Paper PNW-196

1975

## RESEARCH SUMMARY

White fir is an important commercial species in the Fremont National Forest. It has a reputation for being highly defective, mainly because of decay. Cruisers preparing inventory data and timber sales have been handicapped by lack of reliable methods for making defect deductions in their sample trees. Cull rules developed for true fir species in other areas in Oregon, Washington, and California are probably not applicable on the Fremont National Forest because defect usually varies considerably for a given tree species from one area to another.

In this paper two methods are presented for making defect estimates in standing white fir. (1) Defect percentages of gross merchantable volume of trees on the Fremont. Cubic-foot and Scribner board-foot volumes are tabulated by d.b.h.

and age and by d.b.h. only. Constant defect percentages must be added for major indicators, which include Indian paint fungus conks, basal and trunk injuries, frost cracks, and dead or broken tops. Multiple regression equations used to derive the tables are provided. Since the equations can be easily used in computer programs, this method may be most applicable in large scale inventory surveys. (2) Average length deductions below and above major indicators plus flat percentage factors for hidden defect. This method may be most useful to cruisers determining net volumes of sample trees in timber sales.





## Introduction

Reliable methods for estimating defect in standing white fir trees, *Abies concolor* (Gord. & Glend.) Lindl., are needed by cruisers in the Fremont National Forest. Two methods have been developed for estimating defect in grand fir trees, *A. grandis* (Dougl.) Lindl., in the Blue Mountains of Oregon and Washington (Aho 1974). However, these methods are applicable only to the area in which the study was made, because decay usually varies significantly from one geographical area to another (Wagener and Davidson 1954).

The objective of this paper is to present two methods for estimating defect in standing white firs on the Fremont National Forest: (1) Indicator defect percentages, and (2) indicator length deductions with flat percentage factors for "hidden" defect.

1. Multiple regression equations were developed which related cubic- and board-foot defect percentages to tree age and d.b.h. and visible defect indicators.

2. Average length deductions below and above reliable indicators of defect were calculated and flat percentage factors were determined to account for "hidden" defect, which is defect not associated with the major visible indicators used in this study.

The first method is probably most applicable to regional and forest inventories, because the estimating equations can be easily used in computer programs designed to compile survey data from large areas. Since it is only necessary to record tree age, d.b.h., and presence of reliable defect indicators, the use of equations eliminates the subjectivity of cruisers attempting to cull portions of trees based on location of defect indicators.

The second method may be most useful in determining net volumes of sample trees in timber sale areas. Timber sales are generally local and are often carried out by cruisers with years of experience in these localities. Thus, the average length deductions below and above indicators can be adjusted by cruisers familiar with local defect conditions.

## Methods

A total of 133 white firs were selected for study in 18 widely distributed mature (60-149 years) and overmature (150-400 years) stands in the Fremont National Forest (fig. 1). Numbers of trees with various major and minor indicators as well as trees without indicators are listed by diameter classes (table 1). Major indicators of defect were presumed to be the same for white fir on this forest as those previously determined for grand fir in the Blue Mountains and included: Indian paint fungus (*Echinodontium tinctorium* Ell. and Ev.) conks (fig. 2), basal injuries more than 10 years old (fig. 3), trunk wounds more than 10 years old or 1 foot long (fig. 4), frost cracks (fig. 5), and dead (fig. 6) or broken tops (fig. 7). Since decay may at times be associated with minor indicators, such as forks, crooks, dead vertical branches, and small and recent (less than 10 years old) injuries, trees with these indicators were also studied (see Aho (1974) for description and illustration of the minor indicators).

Standing trees selected for study were carefully examined for indicators. D.b.h., location, and description of defect indicators were noted. The trees were then felled, dissected, and examined for decay and other defects. Tree age was determined by a ring count at stump height. Procedures for measuring log and defect volumes and length deductions below and above indicators were the same as those used in the grand fir study in the Blue Mountains (Aho 1974).



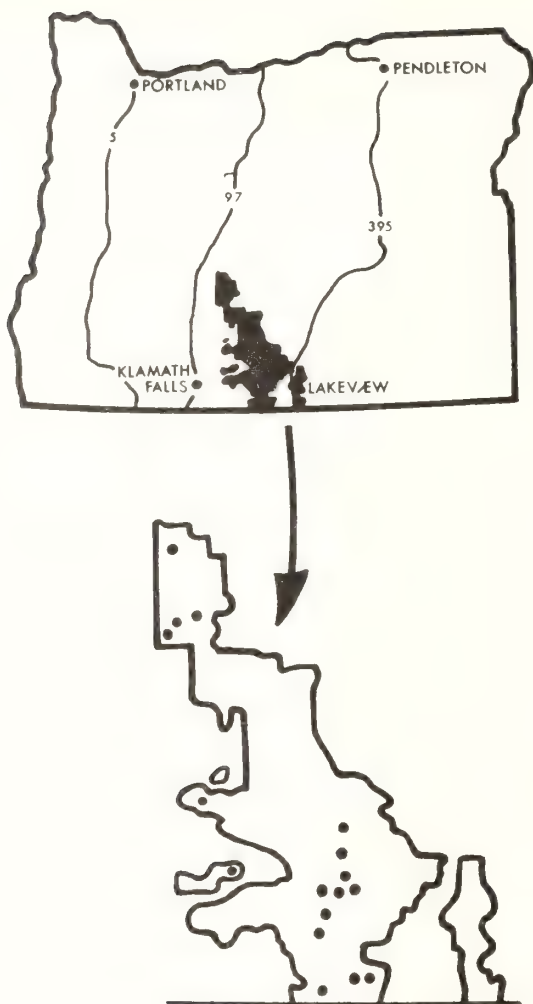


Figure 1.--Location of Fremont National Forest in Oregon and localities where study trees were sampled.

Table 1.--Distribution of various types of indicators on study trees by d.b.h. classes

| D.b.h.<br>class           | Number<br>of<br>sample<br>trees | Trees<br>without<br>indicators | Trees with major indicators        |                   |                   |                 |                              | Trees with minor indicators |        |                              |                                                             |
|---------------------------|---------------------------------|--------------------------------|------------------------------------|-------------------|-------------------|-----------------|------------------------------|-----------------------------|--------|------------------------------|-------------------------------------------------------------|
|                           |                                 |                                | Indian<br>paint<br>fungus<br>conks | Basal<br>injuries | Trunk<br>injuries | Frost<br>cracks | Dead<br>or<br>broken<br>tops | Forks                       | Crooks | Dead<br>vertical<br>branches | Injuries<br>1 foot long<br>or 10 years<br>old <sup>1/</sup> |
| ----- <u>Number</u> ----- |                                 |                                |                                    |                   |                   |                 |                              |                             |        |                              |                                                             |
| 5.0-10.9                  | 11                              | 2                              | 0                                  | 1                 | 2                 | 2               | 2                            | 0                           | 1      | 0                            | 4                                                           |
| 11.0-14.9                 | 23                              | 7                              | 4                                  | 3                 | 3                 | 5               | 6                            | 0                           | 1      | 0                            | 6                                                           |
| 15.0-18.9                 | 37                              | 3                              | 6                                  | 11                | 6                 | 12              | 6                            | 0                           | 1      | 4                            | 1                                                           |
| 19.0-22.9                 | 27                              | 2                              | 6                                  | 11                | 5                 | 13              | 4                            | 1                           | 0      | 0                            | 1                                                           |
| 23.0-26.9                 | 17                              | 3                              | 8                                  | 6                 | 1                 | 9               | 1                            | 1                           | 0      | 0                            | 0                                                           |
| 27.0-30.9                 | 10                              | 0                              | 4                                  | 2                 | 2                 | 5               | 2                            | 2                           | 1      | 1                            | 2                                                           |
| 31.0-34.9                 | 6                               | 3                              | 2                                  | 2                 | 0                 | 2               | 0                            | 0                           | 0      | 0                            | 0                                                           |
| 35.0-38.9                 | 1                               | 1                              | 0                                  | 0                 | 0                 | 0               | 0                            | 0                           | 0      | 0                            | 0                                                           |
| 39.0+                     | 1                               | 0                              | 1                                  | 0                 | 0                 | 0               | 0                            | 0                           | 0      | 0                            | 0                                                           |
| Total                     | <sup>2/</sup> 133               | 21                             | 31                                 | 36                | 19                | 48              | 21                           | 4                           | 4      | 5                            | 14                                                          |

<sup>1/</sup> Includes basal or trunk injuries less than 10 years old and trunk wounds less than 1 foot long.

<sup>2/</sup> Number of trees with various indicators will not total 133 because some trees had more than 1 type of indicator.



Figure 2.--Indian paint fungus conks on a white fir. They are the most important indicator of decay in this species on the Fremont National Forest. When located in the living crown, they can be easily overlooked. Since they do indicate the presence of considerable amounts of decay, cruise results may be significantly affected if conks are missed.

Figure 3.--Old basal wound on white fir. Basal injuries include open or closed wounds, which are in contact with the ground, caused by fire, root rots, falling trees, or mechanical logging equipment. Inconspicuous, old basal injuries nearly grown over may be overlooked if sample trees are not examined carefully.



Figure 4.--Trunk wound on a white fir. Trunk injuries include open or closed wounds below the merchantable top but not in touch with the ground. They may be caused by falling trees, lightning, animals, or logging equipment. Ignore trunk injuries less than 1 foot long or less than 10 years old when computing defect.





Figure 5.--Frost crack on a white fir. Frost cracks are open or closed scars or seams caused by freezing. They are often associated with wetwood, a condition of excessive moisture in the heartwood, usually in the butt log. Bleeding frost cracks at the base of a tree often indicate Indian paint fungus conks higher up the tree.



Figure 6.--White fir with dead top. Recently killed tops should be ignored in computing defect.



Figure 7.--White fir with a broken top. Ignore those recently broken when computing defect.

Defect for cubic-volume measure includes decay only. For board-foot measure, decay, shake, check, and frost cracks are included. No log cull rules were used in cubic-volume defect measurements. In board-foot measurements, logs more than two-thirds defective were considered cull except where merchantable portions of a defective log could be attached to an adjacent sound log.

Multiple regression equations were derived for estimating cubic- and board-foot defect percentages for individual trees. The estimating equations and tables of defect percentages calculated from the equations are presented in this paper.

## Defect Estimation in Individual White Firs

Indicator defect factors for white fir on the Fremont National Forest are presented as (1) percentages of gross merchantable tree cubic-foot and Scribner board-foot volumes and (2) average length deductions below and above indicators, with flat percentage factors for hidden defect. Accurate application of both kinds of defect factors requires familiarity with the definitions of cubic- and board-foot defect and knowledge of indicators associated with defect as previously described in this paper (also see Aho (1974)). Both defect estimating methods will be more accurate when applied to large numbers of trees, although fairly accurate results may be obtained with small samples. In a given timber cruise, only one of the defect estimation methods should be selected; they cannot be used together.

### INDICATOR PERCENTAGE DEFECT FACTORS

Defect percentages derived from multiple regression equations (see table 2,

footnote 1; and table 3, footnote 1) are tabulated by d.b.h. and age (tables 2 and 3). Since it is not always possible to obtain tree ages while cruising, defect percentages are also tabulated by d.b.h. only (tables 4 and 5). Constant defect percentages should be added to those obtained from these tables when various indicators are present.

If equations are to be used in a computer program, it should be realized that defect percentages computed from some combinations of d.b.h., age, and indicators can be less than zero or greater than 100 percent. These percentages should be set at zero or 100 percent.

*Application of percentage defect factors.*-- Sample trees should be carefully examined and the presence of reliable indicators (see figs. 2-7) noted. D.b.h. and age should be measured or estimated. Defect percentages for each tree can then be determined from table 2 or 3 or calculated from the equations in footnote 1 of these tables.

For example, to determine the cubic- and board-foot defect percentages for a 20-inch, 200-year-old white fir without any reliable indicators, simply look at the appropriate columns in the tables. This tree would have deductions of 3 percent of its gross merchantable cubic-foot volume (table 2) and 9 percent of its Scribner board-foot volume (table 3). If the same tree had one or more Indian paint fungus conks and an old broken top, it would be necessary to add 28 percent for the conks and 9 percent for the broken top to the 3-percent deduction previously obtained from table 2 for a total cubic-foot deduction of 40 percent. The additional deductions for these indicators in board-foot measure would be 57 percent for the conks and 4 percent for the broken top for a total board-foot deduction of 70 percent.

[illegible]

1/ Derived from the equation:

$$P_C = -1.425 + 0.056A + 3.727B + 27.910C - 0.346D + 4.156E + 5.254F + 9.038G$$

where A = tree age; B = 1 if 1 or more basal injuries present, 0 if no basal injuries present; C = 1 if 1 or more Indian paint fungus conks present, 0 if no conks present; D = tree diameter outside bark at breast height; E = 1 if 1 or more trunk injuries present, 0 if no trunk injuries present; F = 1 if 1 or more frost cracks present, 0 if no frost cracks present; G = 1 if broken or dead top present, 0 if no broken or dead top present.



Table 3.--Defect expressed in percent of gross merchantable Scribner board-foot volume for white fir trees on the Fremont National Forest by age and d.b.h.<sup>1/</sup> Add these constants for each type of defect indicator present: 1 or more Indian paint fungus conks 57 percent, basal injuries 11 percent, trunk injuries 8 percent, frost cracks 19 percent, and broken or dead tops 4 percent

| Tree<br>d.b.h.<br>(inches) | Tree age (years) |    |     |     |     |     |     |     |     |         |     |     |     |     |     |     |     |     |
|----------------------------|------------------|----|-----|-----|-----|-----|-----|-----|-----|---------|-----|-----|-----|-----|-----|-----|-----|-----|
|                            | 60               | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240     | 260 | 280 | 300 | 320 | 340 | 360 | 380 | 400 |
|                            |                  |    |     |     |     |     |     |     |     | Percent |     |     |     |     |     |     |     |     |
| 11                         | 3                | 6  | 8   | 11  | 13  | 16  | 18  | 21  | 23  | 26      | 28  | 31  | 33  | 36  | 38  | 41  | 43  | 46  |
| 12                         | 2                | 5  | 7   | 10  | 12  | 15  | 17  | 20  | 22  | 25      | 27  | 30  | 32  | 35  | 37  | 40  | 42  | 45  |
| 13                         | 1                | 3  | 6   | 8   | 11  | 13  | 16  | 18  | 21  | 23      | 26  | 28  | 31  | 33  | 36  | 38  | 41  | 43  |
| 14                         | 0                | 2  | 5   | 7   | 10  | 12  | 15  | 17  | 20  | 22      | 25  | 27  | 30  | 32  | 35  | 37  | 40  | 42  |
| 15                         | 0                | 1  | 3   | 6   | 8   | 11  | 13  | 16  | 18  | 21      | 23  | 26  | 28  | 31  | 33  | 36  | 38  | 41  |
| 16                         | 0                | 0  | 2   | 5   | 7   | 10  | 12  | 15  | 17  | 20      | 22  | 25  | 27  | 30  | 32  | 35  | 37  | 40  |
| 17                         | 0                | 0  | 1   | 3   | 6   | 8   | 11  | 13  | 16  | 18      | 21  | 23  | 26  | 28  | 31  | 33  | 36  | 38  |
| 18                         | 0                | 0  | 0   | 2   | 4   | 7   | 9   | 12  | 14  | 17      | 19  | 22  | 24  | 27  | 29  | 32  | 34  | 37  |
| 19                         | 0                | 0  | 0   | 1   | 3   | 6   | 8   | 11  | 13  | 16      | 18  | 21  | 23  | 26  | 28  | 31  | 33  | 36  |
| 20                         | 0                | 0  | 0   | 0   | 2   | 4   | 7   | 9   | 12  | 14      | 17  | 19  | 22  | 24  | 27  | 29  | 32  | 34  |
| 21                         | 0                | 0  | 0   | 0   | 1   | 3   | 6   | 8   | 11  | 13      | 16  | 18  | 21  | 23  | 26  | 28  | 31  | 33  |
| 22                         | 0                | 0  | 0   | 0   | 0   | 2   | 4   | 7   | 9   | 12      | 14  | 17  | 19  | 22  | 24  | 27  | 29  | 32  |
| 23                         | 0                | 0  | 0   | 0   | 0   | 1   | 3   | 6   | 8   | 11      | 13  | 16  | 18  | 21  | 23  | 26  | 28  | 31  |
| 24                         | 0                | 0  | 0   | 0   | 0   | 0   | 2   | 4   | 7   | 9       | 12  | 14  | 17  | 19  | 22  | 24  | 27  | 29  |
| 25                         | 0                | 0  | 0   | 0   | 0   | 0   | 1   | 3   | 6   | 8       | 11  | 13  | 16  | 18  | 21  | 23  | 26  | 28  |
| 26                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 2   | 4   | 7       | 9   | 12  | 14  | 17  | 19  | 22  | 24  | 27  |
| 27                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 3   | 5       | 8   | 10  | 13  | 15  | 18  | 20  | 23  | 25  |
| 28                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 2   | 4       | 7   | 9   | 12  | 14  | 17  | 19  | 22  | 24  |
| 29                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 3       | 5   | 8   | 10  | 13  | 15  | 18  | 20  | 23  |
| 30                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 2       | 4   | 7   | 9   | 12  | 14  | 17  | 19  | 22  |
| 31                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 3   | 5   | 8   | 10  | 13  | 15  | 18  | 20  |
| 32                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 2   | 4   | 7   | 9   | 12  | 14  | 17  | 19  |
| 33                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 3   | 5   | 8   | 10  | 13  | 15  | 18  |
| 34                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 1   | 4   | 6   | 9   | 11  | 14  | 16  |
| 35                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 0   | 3   | 5   | 8   | 10  | 13  | 15  |
| 36                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 0   | 1   | 4   | 6   | 9   | 11  | 14  |
| 37                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 0   | 0   | 3   | 5   | 8   | 10  | 13  |
| 38                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 0   | 0   | 1   | 4   | 6   | 9   | 11  |
| 39                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 0   | 0   | 0   | 3   | 5   | 8   | 10  |
| 40                         | 0                | 0  | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 0   | 0   | 0   | 0   | 1   | 4   | 6   | 9   |

<sup>1/</sup> Derived from the equation:

$$P_b = 9.575 + 0.125A + 11.338B + 56.981C - 1.282D + 8.091E + 18.637F + 3.803G$$

where A = tree age; B = 1 if 1 or more basal injuries present, 0 if no basal injuries present; C = 1 if 1 or more Indian paint fungus conks present, 0 if no conks present; D = tree diameter outside bark at breast height; E = 1 if 1 or more trunk injuries present, 0 if no trunk injuries present; F = 1 if 1 or more frost cracks present, 0 if no frost cracks present; G = 1 if dead or broken tops present, 0 if no dead or broken tops present.

Table 4.--Defect in percent of gross merchantable cubic-foot volume for white fir trees on the Fremont National Forest by d.b.h.<sup>1/</sup> Add these constants for each type of defect indicator present: 1 or more Indian paint fungus conks 29 percent, basal injuries 5 percent, trunk injuries 5 percent, frost cracks 6 percent, and dead or broken tops 9 percent

| Tree d.b.h.<br>(inches) | Defect | Tree d.b.h.<br>(inches) | Defect | Tree d.b.h.<br>(inches) | Defect |
|-------------------------|--------|-------------------------|--------|-------------------------|--------|
| <u>Percent</u>          |        | <u>Percent</u>          |        | <u>Percent</u>          |        |
| 5                       | 4      | 17                      | 1      | 29                      | 0      |
| 6                       | 3      | 18                      | 1      | 30                      | 0      |
| 7                       | 3      | 19                      | 1      | 31                      | 0      |
| 8                       | 3      | 20                      | 1      | 32                      | 0      |
| 9                       | 3      | 21                      | 1      | 33                      | 0      |
| 10                      | 3      | 22                      | 0      | 34                      | 0      |
| 11                      | 2      | 23                      | 0      | 35                      | 0      |
| 12                      | 2      | 24                      | 0      | 36                      | 0      |
| 13                      | 2      | 25                      | 0      | 37                      | 0      |
| 14                      | 2      | 26                      | 0      | 38                      | 0      |
| 15                      | 2      | 27                      | 0      | 39                      | 0      |
| 16                      | 2      | 28                      | 0      | 40                      | 0      |

<sup>1/</sup> Derived from equation:

$$P_c = 4.467 + 4.619B + 29.326C - 0.182D + 4.558E + 6.177F + 9.297G$$

where B = 1 if 1 or more basal injuries present, 0 if no basal injuries present; C = 1 if 1 or more Indian paint fungus conks present, 0 if no conks present; D = tree diameter outside bark at breast height; E = 1 if 1 or more trunk injuries present, 0 if no trunk injuries present; F = 1 if 1 or more frost cracks present, 0 if no frost cracks present; G = 1 if broken or dead top present, 0 if no broken or dead top present.

Table 5.--Defect in percent of gross merchantable Scribner board-foot volume for white fir trees on the Fremont National Forest by d.b.h.<sup>1/</sup> Add these constants for each type of defect indicator present: 1 or more Indian paint fungus conks 60 percent, basal injuries 14 percent, trunk injuries 9 percent, frost cracks 21 percent, and broken or dead tops 4 percent

| Tree d.b.h.<br>(inches) | Defect | Tree d.b.h.<br>(inches) | Defect | Tree d.b.h.<br>(inches) | Defect |
|-------------------------|--------|-------------------------|--------|-------------------------|--------|
| <u>Percent</u>          |        | <u>Percent</u>          |        | <u>Percent</u>          |        |
| 11                      | 13     | 21                      | 4      | 31                      | 0      |
| 12                      | 12     | 22                      | 3      | 32                      | 0      |
| 13                      | 11     | 23                      | 2      | 33                      | 0      |
| 14                      | 10     | 24                      | 1      | 34                      | 0      |
| 15                      | 9      | 25                      | 0      | 35                      | 0      |
| 16                      | 8      | 26                      | 0      | 36                      | 0      |
| 17                      | 7      | 27                      | 0      | 37                      | 0      |
| 18                      | 6      | 28                      | 0      | 38                      | 0      |
| 19                      | 5      | 29                      | 0      | 39                      | 0      |
| 20                      | 4      | 30                      | 0      | 40                      | 0      |

<sup>1/</sup> Derived from equation:

$$P_b = 22.475 + 13.651B + 60.258C - 0.902D + 9.043E + 20.604F + 4.274G$$

where B = 1 if 1 or more basal injuries present, 0 if no basal injuries present; C = 1 if 1 or more Indian paint fungus conks present, 0 if no conks present; D = tree diameter outside bark at breast height; E = 1 if 1 or more trunk injuries present, 0 if no trunk injuries present; F = 1 if 1 or more frost cracks present, 0 if no frost cracks present; G = 1 if dead or broken top present, 0 if no dead or broken top present.

## INDICATOR LENGTH DEDUCTIONS AND FLAT FACTORS FOR HIDDEN DEFECT

Estimates of net volumes in standing trees are often made by timber cruisers by deducting portions of the trees above and below visible indicators of defect. When "visible" defect has been deducted, it is then necessary to apply a flat factor to the total sample volume to account for "hidden" defect. Hidden defect includes shake and decay which are not associated with major indicators and also the small amounts of decay occasionally associated with minor indicators, such as forks, crooks, dead vertical branches, basal and trunk injuries less than 10 years old, and trunk injuries less than 1 foot long. Average length deductions are presented for the major defect indicators (table 6).

(table 6). Where there are two or more indicators in a given segment of a tree, use the indicator that gives the greater deduction. If there is a frost crack near or within a series of Indian paint fungus conks, for instance, base the deduction on the conks. Do not apply the average length deductions to recently killed or broken tops, trunk or basal wounds less than 10 years old, or trunk injuries less than 1 foot long.

In summary, determine total net volume of the sample trees by using the indicator length deduction factors. Total net cubic-foot and Scribner board-foot volumes must then be further reduced by 1 percent and 2 percent, respectively, to account for hidden defect. This, plus any additional deductions for sweep, breakage in felling, and missing parts of trees (broken tops) gives the net sound volume of the sample.

Table 6.--Length deductions for the most reliable indicators of defect on white fir in the Fremont National Forest

| Indicator type            | Trees with defect indicator | Average length deduction |                 |
|---------------------------|-----------------------------|--------------------------|-----------------|
|                           |                             | Below indicator          | Above indicator |
| - - - - Feet - - - -      |                             |                          |                 |
| Indian paint fungus conks | 31                          | 17                       | 20              |
| Basal injuries            | 36                          | --                       | 6               |
| Trunk injuries            | 19                          | 3                        | 2               |
| Frost cracks              | 48                          | 2                        | 3               |
| Dead or broken tops       | 21                          | 3                        | --              |

## Literature Cited

*Application of length deductions and flat factors for hidden defect.*-- If a tree has a series of Indian paint fungus conks and a basal scar, deduct those portions of the tree from 17 feet below the lowest conk to 20 feet above the highest conk and from 6 feet above the top of the basal injury to the bottom of the first log

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1954. Heart rots in living trees. Bot. Rev. 20(2): 61-134.





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1975. Defect estimation for white fir in the Fremont National Forest. USDA For. Serv. Res. Pap. PNW-196, 9 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Two methods for estimating defect in standing white firs are presented for use by timber cruisers in the Fremont National Forest. Defect percentages of gross merchantable cubic-foot and Scribner board-foot volumes are tabulated by d.b.h. only and also by age and d.b.h. Constant defect percentages must then be added for various indicators. The multiple regression equations used to derive the tables are provided. Average length deductions below and above major indicators plus flat percentage factors for hidden defect are presented.

Keywords: White fir, *Abies concolor*, Indian paint fungus, *Echinodontium tinctorium*, defect deduction(-merchantable volume).

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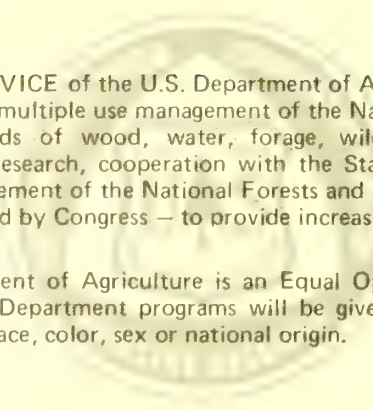
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ALF 754NW-197

# LUMBER RECOVERY FROM LARGE, HIGHLY DEFECTIVE, LOW GRADE COAST DOUGLAS-FIR

Thomas A. Snellgrove  
John W. Henley  
Marlin E. Plank







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# LUMBER RECOVERY FROM LARGE, HIGHLY DEFECTIVE, LOW GRADE COAST DOUGLAS-FIR

## Reference Abstract

Snellgrove, Thomas A., John W. Henley, and  
Marlin E. Plank

1975. Lumber recovery from large, highly defective, low grade Coast Douglas-fir. USDA For. Serv. Res. Paper PNW-197, 23 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A sample of 51 large diameter, highly defective, low grade Coast Douglas-fir trees were processed in a western Oregon sawmill. Lumber grade yields and recovery ratios are presented for two log-scaling and grading practices. The 51 trees generated 117 woods-length logs and 223 sawn-length logs which, in turn, produced about 1/4 million board feet of rough-green lumber. Some key results of this study are compared with an earlier study.

KEYWORDS: Lumber recovery studies, Coast Douglas-fir.

## RESEARCH SUMMARY

Research Paper PNW-197

1975

Estimates of the lumber recovery that can be obtained from the full spectrum of Coast Douglas-fir are needed by forest-land managers, timber buyers, and timber processors for efficient utilization of the resource. Recovery information on Coast Douglas-fir sawtimber from typical commercial stands was presented in an earlier report (Lane et al. 1973). This report presents additional recovery information needed for large diameter, highly defective, low grade Coast Douglas-fir trees.

From a total of 51 sample trees, only No. 2 and No. 3 Sawmill grade logs were generated. The trees averaged about 61-inch d.b.h. and about 56-percent defect. They were processed through a western Oregon mill that normally handled material of this size and type.

General product recovery information is presented in table 1.

There was no significant relationship between percent of lumber recovery (overrun) and diameter, but there was a significant relationship between percent of lumber recovery and percent of estimated defect. Lumber recovery percent increased as defect percent increased, indicating that recovery percent was more closely related to estimated defect than to diameter.

A comparison of lumber grade yields from this study with the study conducted by Lane et al. showed differences that would be expected in view of the different samples. Lumber yields from this study contained 7.1 percent Selects versus 19.5 percent from the Lane et al. study. The percent of Utility and Economy was 74.1 for this study compared with 19.0 for the Lane et al. study.

TABLE 1.--*Total log scale, lumber tally, and cubic volumes by log grade for Coast Douglas-fir sawtimber*

| Log grade          | Number of logs | Log scale <sup>1/</sup> |         | Defect  | Lumber tally |                              | Cubic volume and recovery |                 |                  |                  |
|--------------------|----------------|-------------------------|---------|---------|--------------|------------------------------|---------------------------|-----------------|------------------|------------------|
|                    |                | Gross                   | Net     |         | Volume       | Recovery ratio <sup>2/</sup> | Log                       | Lumber recovery | Sawdust recovery | Residue recovery |
|                    |                | - - Board feet - -      |         | Percent | Board feet   | Percent                      | Cubic feet                | - - - - -       | Percent          | - - - - -        |
| Sawn-length logs:  |                |                         |         |         |              |                              |                           |                 |                  |                  |
| No. 2 Sawmill      | 62             | 102,500                 | 61,670  | 39.8    | 96,191       | 156                          | 12,589                    | 65              | 8                | 27               |
| No. 3 Sawmill      | 161            | 175,130                 | 114,250 | 34.8    | 167,390      | 147                          | 22,982                    | 61              | 8                | 31               |
| Total or average   | 223            | 277,630                 | 175,920 | 36.6    | 263,581      | 150                          | 35,571                    | 62              | 8                | 30               |
| Woods-length logs: |                |                         |         |         |              |                              |                           |                 |                  |                  |
| No. 2 Sawmill      | 36             | 102,400                 | 53,800  | 47.5    | 109,293      | 203                          | 15,153                    | 61              | 8                | 31               |
| No. 3 Sawmill      | 81             | 111,830                 | 57,750  | 48.4    | 136,664      | 237                          | 18,517                    | 62              | 8                | 30               |
| Total or average   | 117            | 214,230                 | 111,550 | 47.9    | 245,957      | 220                          | 33,670                    | 62              | 8                | 30               |

<sup>1/</sup> Sawn-length logs: as scaled by Bureau of Land Management check scaler by BLM rules, Scribner Decimal C log rule.  
Woods-length logs: as scaled by Forest Service scaler by west-side rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

## Introduction

Coast Douglas-fir sawtimber,<sup>1/</sup> one of the most important raw material resources in the United States, is found over a variety of environmental conditions in Washington, Oregon, and California. Stem quality, size, and defect vary greatly over the entire range of Coast Douglas-fir; thus, quality and value of its end products vary considerably. Because of this variability, correct valuation of this timber resource is very important. Estimates of the lumber recovery that can be obtained from the full spectrum of Douglas-fir are needed by forest-land managers, timber buyers, and timber processors for efficient utilization of the resource.

Information on recovery of lumber from Coast Douglas-fir has been reported by Lane et al. (1973). They presented recovery information for Douglas-fir trees selected from typical commercial sawtimber stands. However, additional recovery information was needed for atypical Douglas-fir sawtimber occurring in localized areas throughout its range; specifically, large diameter, highly defective, low grade Coast Douglas-fir trees.

The Pacific Northwest Forest and Range Experiment Station, Bureau of Land Management (U. S. Department of the Interior), Pacific Northwest Region (Region 6) of the National Forest System, and Hull-Oakes Lumber Company cooperated on this study. This report presents information on the grade and volume of various lumber items produced under current industry manufacturing practices from this highly defective portion of the resource in Oregon.

---

<sup>1/</sup>Coast Douglas-fir refers to the botanical variety of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*.

## Study Procedures

### TIMBER SAMPLE

The 51 study trees were selected from a timber sale in the Coast Ranges of Oregon. Logs cut from these trees were processed in a sawmill near Monroe, Oregon. The trees were representative of the large diameter, highly defective, low grade trees that occur within the Oregon range of Coast Douglas-fir. These trees were considered nonmerchantable when the stand was logged 30 to 40 years ago. Consequently, only grades No. 2 Sawmill and No. 3 Sawmill logs were produced. Some average characteristics of the trees selected were:

|                |         |                 |
|----------------|---------|-----------------|
| D. b. h.       | Range   | 40 to 76 inches |
|                | Average | 61.3            |
| Total height   | Range   | 125 to 216 feet |
|                | Average | 171.2           |
| Defect percent | Range   | 8.0 to 92.0     |
|                | Average | 55.7            |

The objective was to obtain additional saw-log recovery information for a specific segment of the Coast Douglas-fir timber resource. The sample was not intended to be representative of the normal mix of Douglas-fir sawtimber that a mill would receive in a specified length of time.

### LOGGING, IDENTIFICATION, SCALING, AND GRADING

The study trees were felled and bucked into logs by the cooperating logging contractor according to normal industry practice. Each log was numbered to identify its origin by tree and position in the tree.

The visible characteristics of each log were critically examined and recorded. Thus, the relationship of the external characteristics of a log to its yield by lumber



grade could be analyzed.

The study logs were trucked to the cooperating mill where they were graded and scaled in the lengths as delivered from the woods in accordance with practices used in the west-side Douglas-fir region.<sup>2/</sup> The specifications are a modified version of the uniform Bureau rules,<sup>3/</sup> for use in cruising standing trees where log end defects are not considered in determination of grade. The scale was also determined by Bureau rules (see footnote 3).

A Bureau of Land Management check scaler, applying the BLM rules,<sup>4/</sup> rescaled and regraded the study logs after they were bucked for sawing. These scaling rules follow National Forest Log Scaling Handbook rules,<sup>5/</sup> except for scale deduction procedures. In this scale, logs up to and including 20 feet in length are scaled as one segment, and diameters are rounded. Volumes are expressed in Scribner Decimal C rule in both scaling practices. For simplification in this report, the scale taken by the U.S. Forest Service check scaler will be called the "woods-length" scale, and the scale taken by the BLM check scaler will be called the "sawn-length" scale.

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<sup>2/</sup> U.S. Forest Service R-6 Supplement to National Forest Log Scaling Handbook for West-side Log Scaling. October 1965. U.S. Forest Service Log Grade Description for Douglas-fir. Form R-6 2440-19D, March 1965.

<sup>3/</sup> Official Log Scaling and Grading Rules for the Columbia River Log Scaling and Grading Bureau, Puget Sound Log Scaling and Grading Bureau, Grays Harbor Log Scaling and Grading Bureau, Southern Oregon Log Scaling and Grading Bureau, Northern California Log Scaling and Grading Bureau. January 1, 1969.

<sup>4/</sup> Bureau of Land Management Log Scaling Manual, May 1970.

<sup>5/</sup> National Forest Log Scaling Handbook U.S. Department of Agriculture Forest Service Handbook 2409. 11. Amended January 1969.

The 51 sample trees produced 117 merchantable woods-length logs and 223 merchantable sawn-length logs. Distribution of these logs by scaling diameter, length, and grade is shown in tables 2 and 3. As is apparent from table 2, logs to be processed were bucked to 28 feet or less.

## SAWING, LUMBER GRADING, AND TALLYING

The logs were sawn under normal production conditions at the study sawmill. Equipment included a band headsaw, an edger, a vertical band resaw, and a gang trimmer.

The logs were sawn to obtain the highest value from each log following normal manufacturing procedures for producing board, dimension, and select items. The mill, however, did not produce any shop items, and their normal production of timbers was probably higher than most other Oregon sawmills manufacturing Douglas-fir.

Log identity was maintained on each piece of lumber throughout the manufacturing process to the final point of grading and tally. A West Coast Lumber Inspection Bureau grading inspector graded all study lumber on the green chain by West Coast Lumber Inspection Bureau (1970) rules for Douglas-fir. Each lumber item produced was placed into one of these grades:

|                     |                       |
|---------------------|-----------------------|
| B and Better Select | No. 1 or Construction |
| C Select            | No. 2 or Standard     |
| D Select            | No. 3 or Utility      |
| Select Structural   | Economy               |

In subsequent tables, figures, and discussion, lumber grades No. 1, No. 2, and No. 3 include Construction, Standard, and Utility, respectively.

Each piece of lumber was tallied by its shipping dimensions, grade, and log number.

TABLE 2.--Number of woods-length and sawn-length Coast Douglas-fir logs by length and grade

| Log length (feet) | Woods-length logs |               |            | Sawn-length logs |               |            |
|-------------------|-------------------|---------------|------------|------------------|---------------|------------|
|                   | Grade             |               | All grades | Grade            |               | All grades |
|                   | No. 2 Sawmill     | No. 3 Sawmill |            | No. 2 Sawmill    | No. 3 Sawmill |            |
| 8                 | --                | 1             | 1          | --               | 1             | 1          |
| 10                | --                | 1             | 1          | --               | 1             | 1          |
| 12                | --                | 1             | 1          | 2                | 1             | 3          |
| 14                | --                | 3             | 3          | 7                | 16            | 23         |
| 16                | 1                 | 2             | 3          | 2                | 15            | 17         |
| 18                | --                | 1             | 1          | 11               | 19            | 30         |
| 20                | 1                 | 2             | 3          | 11               | 24            | 35         |
| 22                | 1                 | 8             | 9          | 18               | 42            | 60         |
| 24                | --                | 1             | 1          | 4                | 14            | 18         |
| 26                | --                | 3             | 3          | 5                | 15            | 20         |
| 28                | 1                 | 2             | 3          | 2                | 13            | 15         |
| 30                | 1                 | 1             | 2          | --               | --            | --         |
| 32                | 1                 | 2             | 3          | --               | --            | --         |
| 34                | --                | 3             | 3          | --               | --            | --         |
| 36                | --                | 1             | 1          | --               | --            | --         |
| 38                | --                | 2             | 2          | --               | --            | --         |
| 40                | 21                | 32            | 53         | --               | --            | --         |
| 42                | --                | 2             | 2          | --               | --            | --         |
| 44                | 7                 | 4             | 11         | --               | --            | --         |
| 46                | --                | 1             | 1          | --               | --            | --         |
| 48                | 2                 | 6             | 8          | --               | --            | --         |
| 50                | --                | --            | --         | --               | --            | --         |
| 52                | --                | 1             | 1          | --               | --            | --         |
| 54                | --                | --            | --         | --               | --            | --         |
| 56                | --                | 1             | 1          | --               | --            | --         |
| Total             | 36                | 81            | 117        | 62               | 161           | 223        |

TABLE 3.--Number of woods-length and sawn-length Coast Douglas-fir logs by diameter and grade

| Scaling diameter (inches) | Woods-length logs |               |            | Sawn-length logs |               |            |
|---------------------------|-------------------|---------------|------------|------------------|---------------|------------|
|                           | Grade             |               | All grades | Grade            |               | All grades |
|                           | No. 2 Sawmill     | No. 3 Sawmill |            | No. 2 Sawmill    | No. 3 Sawmill |            |
| 10                        | --                | 2             | 2          | --               | 2             | 2          |
| 11                        | --                | 5             | 5          | --               | 3             | 3          |
| 12                        | --                | --            | --         | --               | 2             | 2          |
| 13                        | --                | 4             | 4          | 1                | 1             | 2          |
| 14                        | 1                 | 3             | 4          | 1                | 2             | 3          |
| 15                        | --                | 3             | 3          | 1                | 4             | 5          |
| 16                        | --                | 2             | 2          | --               | 1             | 1          |
| 17                        | --                | 2             | 2          | --               | 4             | 4          |
| 18                        | --                | 6             | 6          | --               | 4             | 4          |
| 19                        | 1                 | 3             | 4          | 1                | 7             | 8          |
| 20                        | --                | 3             | 3          | --               | 3             | 3          |
| 21                        | --                | 2             | 2          | 1                | 3             | 4          |
| 22                        | --                | 4             | 4          | --               | 8             | 8          |
| 23                        | 1                 | 2             | 3          | 1                | 3             | 4          |
| 24                        | --                | 3             | 3          | --               | 8             | 8          |
| 25                        | 2                 | 1             | 3          | 2                | 4             | 6          |
| 26                        | 1                 | 2             | 3          | --               | 6             | 6          |
| 27                        | --                | --            | --         | --               | 3             | 3          |
| 28                        | 1                 | 2             | 3          | 3                | 5             | 8          |
| 29                        | --                | 2             | 2          | 2                | 4             | 6          |
| 30                        | 1                 | 1             | 2          | --               | 4             | 4          |
| 31                        | --                | 3             | 3          | 1                | 8             | 9          |
| 32                        | 2                 | --            | 2          | 3                | 8             | 11         |
| 33                        | 1                 | 3             | 4          | 1                | 2             | 3          |
| 34                        | 2                 | 2             | 4          | 1                | 4             | 5          |
| 35                        | --                | 5             | 5          | --               | --            | --         |
| 36                        | 2                 | 2             | 4          | 3                | 5             | 8          |
| 37                        | --                | --            | --         | --               | 9             | 9          |
| 38                        | 2                 | 4             | 6          | 2                | 3             | 5          |
| 39                        | 1                 | --            | 1          | 2                | 3             | 5          |
| 40                        | 3                 | 1             | 4          | 1                | 2             | 3          |
| 41                        | --                | --            | --         | 4                | 5             | 9          |
| 42                        | 2                 | --            | 2          | 1                | 3             | 4          |
| 43                        | 1                 | --            | 1          | 3                | 2             | 5          |
| 44                        | 2                 | 2             | 4          | 2                | 4             | 6          |
| 45                        | 3                 | 1             | 4          | 5                | 2             | 7          |
| 46                        | 2                 | 2             | 4          | 2                | 7             | 9          |
| 47                        | 1                 | --            | 1          | 2                | 3             | 5          |
| 48                        | 1                 | 1             | 2          | 2                | 1             | 3          |
| 49                        | 1                 | 2             | 3          | --               | 1             | 1          |
| 50                        | --                | --            | --         | 1                | 1             | 2          |
| 51                        | --                | 1             | 1          | 1                | --            | 1          |
| 52                        | --                | --            | --         | 1                | 2             | 3          |
| 53                        | --                | --            | --         | 1                | 2             | 3          |
| 54                        | 1                 | --            | 1          | 2                | 1             | 3          |
| 55                        | --                | --            | --         | 4                | 1             | 5          |
| 56                        | --                | --            | --         | --               | 1             | 1          |
| 57                        | 1                 | --            | 1          | --               | --            | --         |
| 58                        | --                | --            | --         | 1                | --            | 1          |
| 59                        | --                | --            | --         | 1                | --            | 1          |
| 60                        | --                | --            | --         | 1                | --            | 1          |
| 61                        | --                | --            | --         | --               | --            | --         |
| 62                        | --                | --            | --         | 1                | --            | 1          |
| Total                     | 36                | 81            | 117        | 62               | 161           | 223        |

The tally was made on the green chain; the grader pencil-ripped and trimmed when necessary. The anticipated surfaced tally was recorded.

## COMPILATION OF DATA

In addition to lumber grade and board-foot volume data collected, cubic volumes of logs, lumber, residues, and sawdust were calculated for all study logs.

The gross cubic-foot log volume was computed by the formula:

$$V = 0.00181805 L(D_s^2 + D_s D_e + D_e^2)$$

where V = gross cubic-foot log volume

$D_s$  = diameter in inches of small end of log

$D_e$  = diameter in inches of large end of log

L = log length in feet

The lumber cubic volumes were based on average rough green dimensions of the various lumber sizes. The average dimensions were obtained by measuring samples of all lumber items produced throughout the study.

Sawdust cubic volumes were calculated by using an average saw kerf of 0.25 inch and the computed surface area of the rough green lumber from each log. Cubic volume of residue was obtained by subtracting the lumber and sawdust volumes from the gross cubic volume of woods-length logs. Thus, the residue volume included a small amount of sawdust from the production of slabs, edgings, and trim ends. Note that the gross cubic volume is based on scale lengths, so an average trim allowance of 6 inches would increase the gross cubic volume of the average log by about 2.4 percent, and there would be a corresponding increase in the volume of residue.

The lumber grade yield from the woods-length logs was obtained by combining the lumber recovery from the sections sawn from each woods-length log.

## Results and Discussion

Table 4 summarizes the total log scale, lumber tally, and cubic volume of the logs in the study for each log grade and for all grades combined. A more detailed breakdown of these data, including lumber grade yields by scaling diameter and log grade, is presented in tables 8 through 17 in the

TABLE 4.--- Log scale, lumber tally, and cubic volume of logs in the study

| Log grade          | Number of logs | Log scale <sup>1/</sup> |                    |         | Defect  | Lumber tally                 |                    | Cubic volume       |                                     |                    |                    |  |
|--------------------|----------------|-------------------------|--------------------|---------|---------|------------------------------|--------------------|--------------------|-------------------------------------|--------------------|--------------------|--|
|                    |                | Gross                   | Net                | Volume  |         | Recovery ratio <sup>2/</sup> | Log                | Lumber             | Lumber recovery ratio <sup>3/</sup> | Sawdust            | Residue            |  |
|                    |                | - - Board feet - -      | - - Board feet - - | Percent |         | Percent                      | - - Cubic feet - - | - - Cubic feet - - | Percent                             | - - Cubic feet - - | - - Cubic feet - - |  |
| Sawn-length logs:  |                |                         |                    |         |         |                              |                    |                    |                                     |                    |                    |  |
| No. 2 Sawmill      | 62             | 102,500                 | 61,670             | 40      | 96,191  | 156                          | 12,589             | 8,128              | 65                                  | 1,071              | 3,390              |  |
| No. 3 Sawmill      | 161            | 175,130                 | 114,250            | 35      | 167,390 | 147                          | 22,982             | 14,091             | 61                                  | 1,780              | 7,111              |  |
| Total or average   | 223            | 277,630                 | 175,920            | 37      | 263,581 | 150                          | 35,571             | 22,218             | 62                                  | 2,851              | 10,502             |  |
| Woods-length logs: |                |                         |                    |         |         |                              |                    |                    |                                     |                    |                    |  |
| No. 2 Sawmill      | 36             | 102,400                 | 53,800             | 48      | 109,293 | 203                          | 15,154             | 9,206              | 61                                  | 1,216              | 4,732              |  |
| No. 3 Sawmill      | 81             | 111,830                 | 57,750             | 48      | 136,664 | 237                          | 18,517             | 11,517             | 62                                  | 1,430              | 5,570              |  |
| Total or average   | 117            | 214,230                 | 111,550            | 48      | 245,957 | 220                          | 33,670             | 20,723             | 62                                  | 2,646              | 10,301             |  |

<sup>1/</sup> Sawn-length logs: as scaled by Bureau of Land Management scaler by BLM rules, Scribner Decimal C log rule. Woods-length logs: as scaled by Forest Service scaler by west-side log scaling rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

<sup>3/</sup> Lumber cubic volume as percentage of log cubic volume.

appendix. Data considered of value to the reader are presented for both sawn-length and woods-length logs. In general, only sawn-length log data are discussed.

## DEFECT

The relationship of scale defect to scaling diameter for both sawn-length and woods-length logs is shown in figure 1.

for woods-length logs is substantially higher than for sawn-length logs, i.e., 47.9 compared with 36.9, probably because the more defective portions of the woods-length logs were culled as they were bucked to sawn-lengths. For the sawn-length logs, there was also a slight difference in percent of defect between log grades, as shown in table 4. The No. 2 Sawmill logs on the average were 5 percent more defective than the No. 3 Sawmill logs.

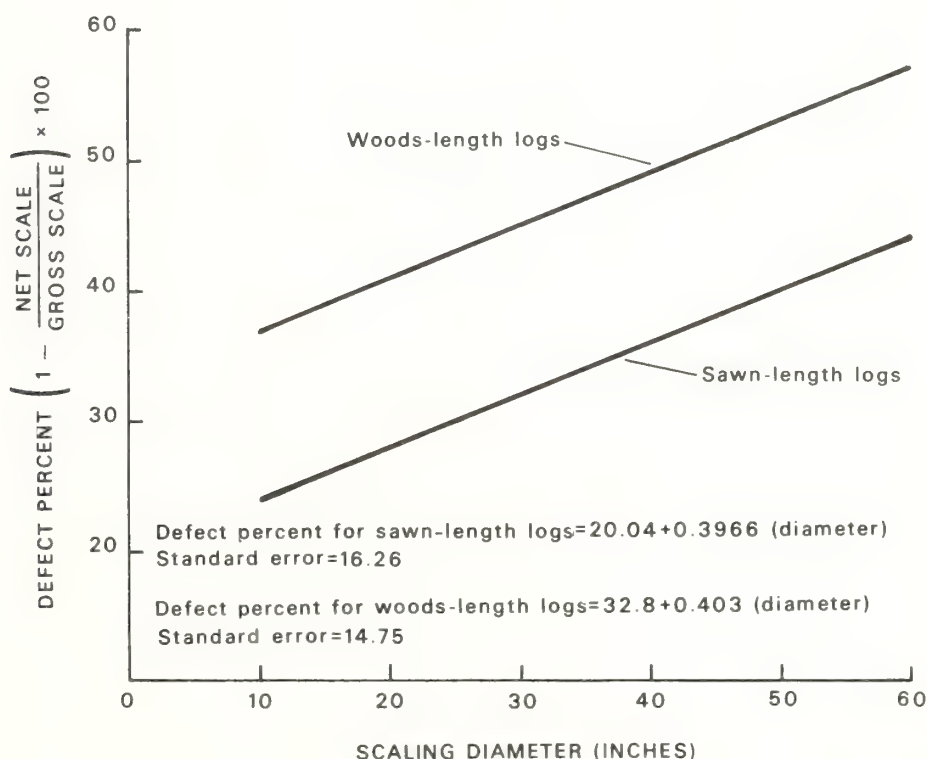


Figure 1.--Relationship of scale defect to scaling diameter.

As would be expected, percent of defect increased with an increase in scaling diameter for both sawn-length and woods-length logs. The average percent of defect

These differences in defect probably account for some of the differences in lumber yields that will be shown later.



## LUMBER RECOVERY

As shown in table 4, the 223 sawn-length logs produced 263,581 board feet of lumber, and the 117 woods-length logs produced 245,957 board feet. The difference between the lumber tally volume produced from the sawn-length and the woods-length logs is due to more woods-length logs being scaled as cull (defect greater than 66-2/3 percent).

The distribution in percent of lumber volume of the sawn-length logs is summarized by grade, thickness, and width in table 5. Approximately 63 percent of the production was in 2-inch dimension items, 21 percent in 5-inch and thicker items, about 15 percent in 3-inch material, and the remaining 1 percent in 1-inch boards. The thickness, width, and grade distribution of the lumber volume in the woods-length logs are, for all practical purposes, the same as for sawn-length logs.

## LUMBER GRADE YIELDS

Yields by lumber grades, expressed as a percent of lumber tally volume by log grade for sawn-length and woods-length logs, are shown in table 6. Eight lumber items were produced. For all sawn-length logs, approximately 74 percent of the lumber produced was in No. 3 and Economy grades, indicating both high defect and poor quality of the study logs. Table 6 also shows that, for sawn-length No. 2 Sawmill logs, about 15 percent of the lumber volume was in Selects compared with less than 3 percent for the No. 3 Sawmill logs. No. 2 Sawmill logs produced a lower percentage of No. 3 and Economy grade lumber than the No. 3 Sawmill logs; i. e., 68 percent compared with 77 percent.

Lumber grade yields, expressed as a percent of the lumber tally volume by scaling diameter for individual log grades, are shown

TABLE 5.--Distribution of lumber volume by grade, thickness, and width from Coast Douglas-fir sawn-length logs

| Thickness        | Width      | Volume                         | Grade               |          |          |                   |                        |                    |                   |         |         |
|------------------|------------|--------------------------------|---------------------|----------|----------|-------------------|------------------------|--------------------|-------------------|---------|---------|
|                  |            |                                | B and Better Select | C Select | D Select | Select Structural | No. 1 and Construction | No. 2 and Standard | No. 3 and Utility | Economy | All     |
| -- Inches --     | Board feet | Percent of total lumber volume |                     |          |          |                   |                        |                    |                   |         |         |
| 1                | 3.4        | 719                            | 0                   | 0.08     | 0.01     | 0.01              | 0.01                   | 0.02               | 0.07              | 0.06    | 0.26    |
|                  | 6          | 780                            | 0                   | .07      | .01      | .01               | .05                    | .03                | .07               | .06     | .30     |
|                  | 8          | 1,187                          | 0                   | .06      | 0        | 0                 | .07                    | .08                | .15               | .08     | .44     |
|                  | 10         | 55                             | 0                   | 0        | 0        | 0                 | .01                    | 0                  | 0                 | .01     | .02     |
|                  | 12         | 40                             | 0                   | 0        | 0        | 0                 | 0                      | 0                  | 0                 | .02     | .02     |
| Total            | 2,781      | 0                              | .21                 | .02      | .02      | .14               | .13                    | .29                | .23               | 1.04    |         |
| 2                | 3.4        | 8,835                          | 0                   | .60      | .11      | .04               | .13                    | .15                | .80               | 1.52    | 3.35    |
|                  | 6          | 11,201                         | 0                   | .70      | .22      | .15               | .23                    | .32                | .97               | 1.66    | 4.25    |
|                  | 8          | 52,207                         | .04                 | 1.36     | .38      | .35               | 1.01                   | 1.98               | 5.49              | 9.19    | 19.80   |
|                  | 10         | 43,372                         | 0                   | .51      | .06      | .31               | .80                    | 1.84               | 6.20              | 6.75    | 16.47   |
|                  | 12         | 49,835                         | 0                   | .22      | .07      | .56               | 1.06                   | 2.42               | 8.25              | 6.32    | 18.90   |
| Total            | 165,450    | .04                            | 3.39                | .84      | 1.41     | 3.23              | 6.71                   | 21.71              | 25.44             | 62.77   |         |
| 3                | 4          | 1,899                          | 0                   | .12      | .02      | 0                 | .04                    | .04                | .18               | .32     | .72     |
|                  | 6          | 6,187                          | 0                   | 1.07     | .13      | .06               | .19                    | .13                | .44               | .33     | 2.34    |
|                  | 8          | 4,102                          | 0                   | 1.03     | .03      | .02               | .06                    | .10                | .19               | .13     | 1.56    |
|                  | 10         | 6,356                          | 0                   | .15      | 0        | .03               | .05                    | .05                | .68               | 1.44    | 2.41    |
|                  | 12         | 20,214                         | 0                   | .06      | .02      | .15               | .46                    | .89                | 2.84              | 3.25    | 7.67    |
| Total            | 38,758     | 0                              | 2.43                | .20      | .26      | .80               | 1.21                   | 4.33               | 5.47              | 14.70   |         |
| 5                | 8          | 21,126                         | 0                   | 0        | 0        | 0                 | .02                    | .04                | 1.30              | 6.65    | 8.01    |
|                  | 10         | 26,826                         | 0                   | .02      | .02      | 0                 | .31                    | 2.68               | 5.34              | 1.82    | 10.18   |
|                  | 12         | 8,640                          | 0                   | 0        | 0        | 0                 | .05                    | 1.73               | 1.40              | .09     | 3.28    |
| Total            | 56,592     | 0                              | .02                 | .02      | 0        | .38               | 4.45                   | 8.04               | 8.56              | 21.47   |         |
| Total, all items |            | 263,581                        | .04                 | 6.05     | 1.08     | 1.69              | 4.55                   | 12.50              | 34.37             | 39.70   | 1/99.98 |

<sup>1/</sup> The percentages may not add to an even 100 percent because of rounding.



TABLE 6.--Average yields from first log-length logs, lumber grade expressed as a percent of total volume

| Log grade          | Number of logs | Lumber tally volume | Lumber grade        |          |          |                   |                        |                    |                   |         |
|--------------------|----------------|---------------------|---------------------|----------|----------|-------------------|------------------------|--------------------|-------------------|---------|
|                    |                |                     | B and Better Select | C Select | D Select | Select Structural | No. 1 and Construction | No. 2 and Standard | No. 3 and Utility | Economy |
| Board feet         |                |                     |                     |          |          |                   |                        |                    |                   |         |
| Sawn-length logs:  |                |                     |                     |          |          |                   |                        |                    |                   |         |
| No. 2 Sawmill      | 62             | 96,191              | 0.04                | 12.38    | 2.25     | 3.08              | 5.33                   | 8.61               | 27.64             | 40.67   |
| No. 3 Sawmill      | 161            | 167,390             | .05                 | 2.38     | .39      | .91               | 4.11                   | 14.74              | 38.28             | 39.14   |
| Total or average   | 223            | 263,581             | .04                 | 6.03     | 1.07     | 1.70              | 4.55                   | 12.51              | 34.40             | 39.70   |
| Woods-length logs: |                |                     |                     |          |          |                   |                        |                    |                   |         |
| No. 2 Sawmill      | 36             | 109,293             | .02                 | 9.91     | 1.68     | 2.42              | 4.98                   | 10.25              | 27.81             | 42.93   |
| No. 3 Sawmill      | 81             | 136,664             | .03                 | 2.35     | .39      | .85               | 4.10                   | 14.03              | 39.95             | 38.30   |
| Total or average   | 117            | 245,957             | .02                 | 5.71     | .97      | 1.54              | 4.49                   | 12.35              | 34.56             | 40.36   |

in tables 14-17 of the appendix. The same information is shown in curve form for sawn-length logs in figures 2 and 3. The variability that occurs in lumber yield has been smoothed by curving to indicate yield patterns. These curves show that there is a statistically significant increase in the percentage of Selects with an increase in scaling diameter for No. 3 Sawmill logs, but not for No. 2 Sawmill logs. For both No. 2 and No. 3 Sawmill logs, the percentage of Economy lumber increased as the scaling diameter increased at the expense of the percentage of Select Structural, No. 1,

and No. 2 lumber. The data also indicate no significant relationship between scaling diameter and the percentage of Utility grade lumber for either log grade.

#### LUMBER RECOVERY PERCENT (OVERRUN)

For the sawn-length logs, there was no statistically significant relationship between lumber recovery percent (overrun) and diameter by individual log grade nor for both grades combined. The net scale for the sawn-length logs in the study was 175,920

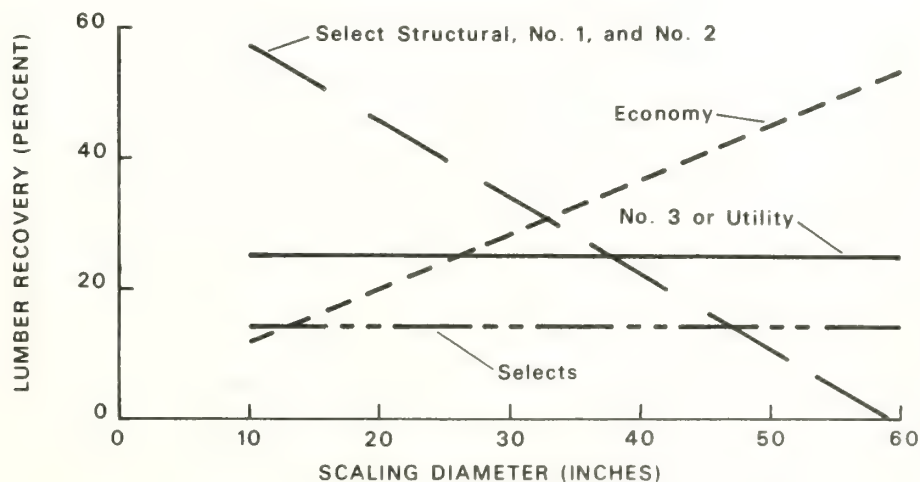


Figure 2.--Lumber grade recovery expressed as a percent of lumber volume over diameter for sawn-length No. 2 Sawmill logs.

board feet while 263,581 board feet of lumber was actually produced, thus giving a recovery of 150 percent (fig. 4). No. 2 Sawmill logs had an average recovery

of 156 percent compared with 147 percent for No. 3 Sawmill logs. However, this difference was not statistically significant.

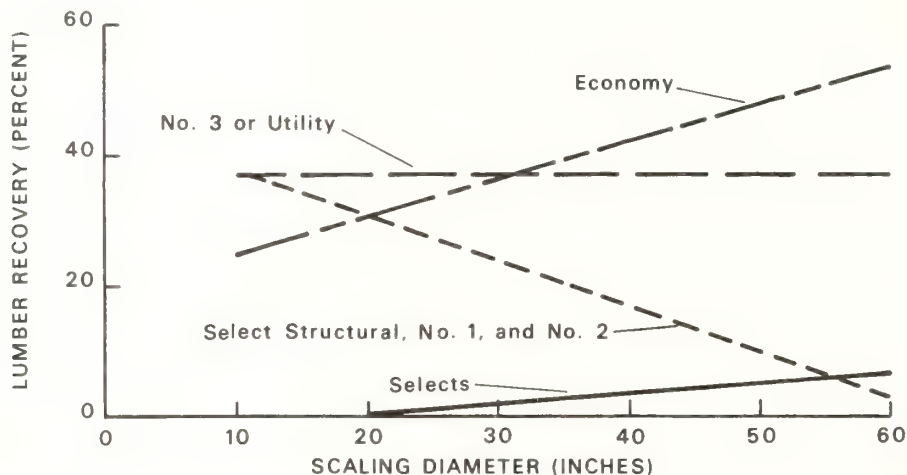


Figure 3.--Lumber recovery expressed as a percent of lumber tally volume over diameter for sawn-length No. 3 Sawmill logs.

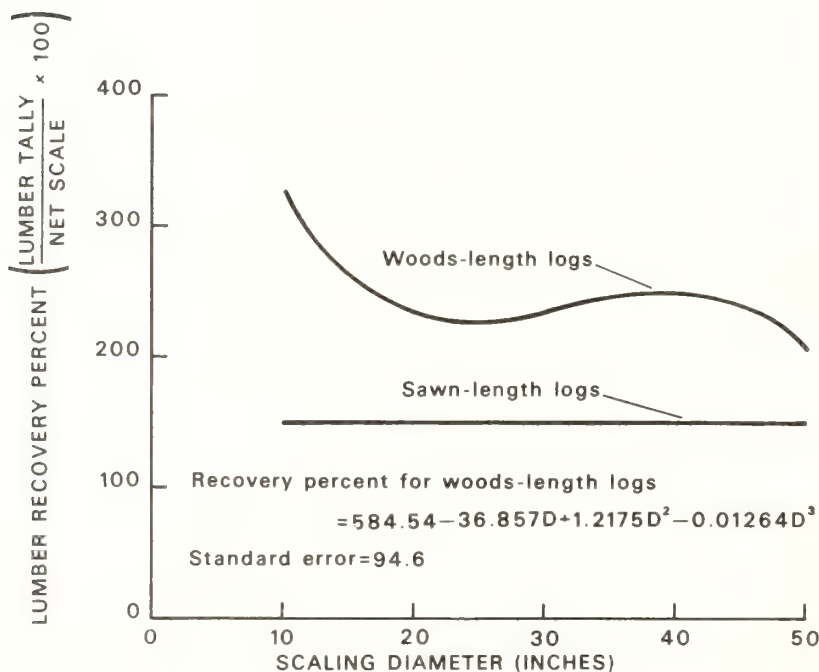


Figure 4.--Relationship of net log scale-lumber recovery percent to scaling diameter.

The reason for the lack of significance between recovery percent and diameter for sawn-length logs probably lies in the sample. As stated in the sampling section of this paper, the study logs represented a specific segment of the total population and were not intended to be representative of the total population. The study trees had a minimum d.b.h. of 40 inches, producing a disproportionate share of large, highly defective logs.

On the other hand, figure 5 shows a

significant relationship between recovery percent and defect percent. Recovery percent increased as defect percent increased, indicating that, at least for this sample, recovery percent was more closely related to estimated defect than to diameter. A stepwise multiple regression analysis substantiated this hypothesis. Recovery percent for woods-length logs is also shown in figure 4. Due to the different scale basis, the woods-length percents are consistently higher.

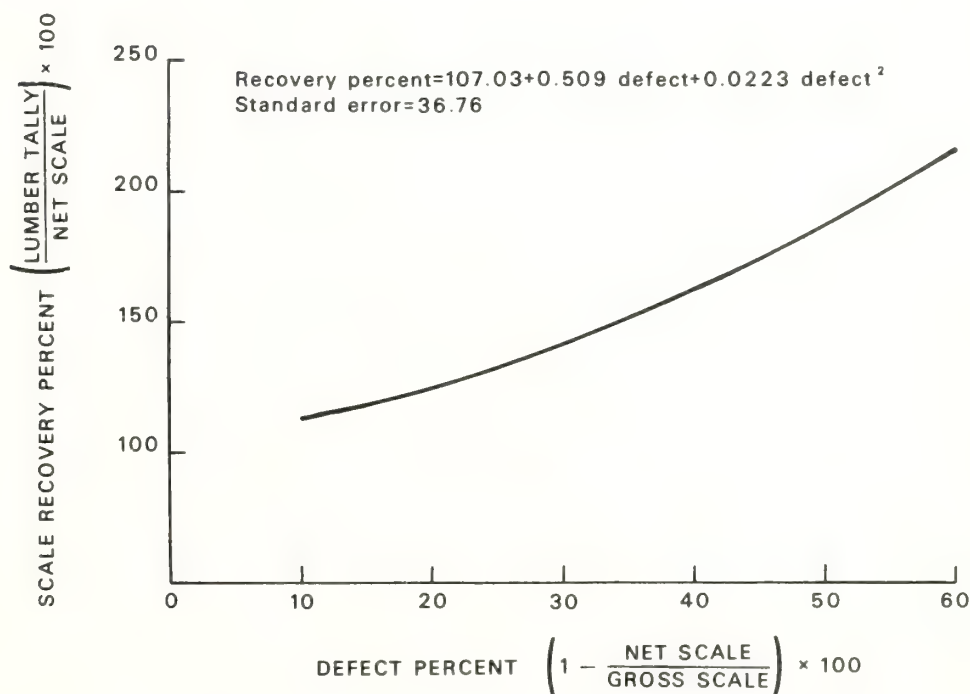


Figure 5.--Relationship of net log scale-lumber recovery percent to defect percent, sawn-length logs.

## CUBIC RATIOS

The relationship of the lumber cubic volume recovery percent to scaling diameter is shown in figure 6. As would be expected, cubic recovery increases with an increase in diameter up to about 40 inches, then decreases. The reduction in cubic recovery at about 40 inches is probably due to the higher defect percentages in the larger diameter logs.

On the average, about 62.5 percent of the cubic content of the sawn-length logs was manufactured into rough green lumber, and about 8 percent of the volume was in sawdust. The remaining 29.5 percent of the cubic content of the logs could be considered mill residue, a substantial

proportion of which would be available for chipping.

Figure 7 shows the relationship of board feet of lumber produced per cubic foot of log input. As would be expected, the general shape of the curve is similar to the cubic recovery percent curve. For sawn-length logs, an average of 7.2 board feet of lumber was produced for every cubic foot of log input.

## COMPARATIVE RESULTS

A few key results of this study will be compared with results from an earlier Coast Douglas-fir study (Lane et al. 1973). Results of these two studies are shown in table 7.

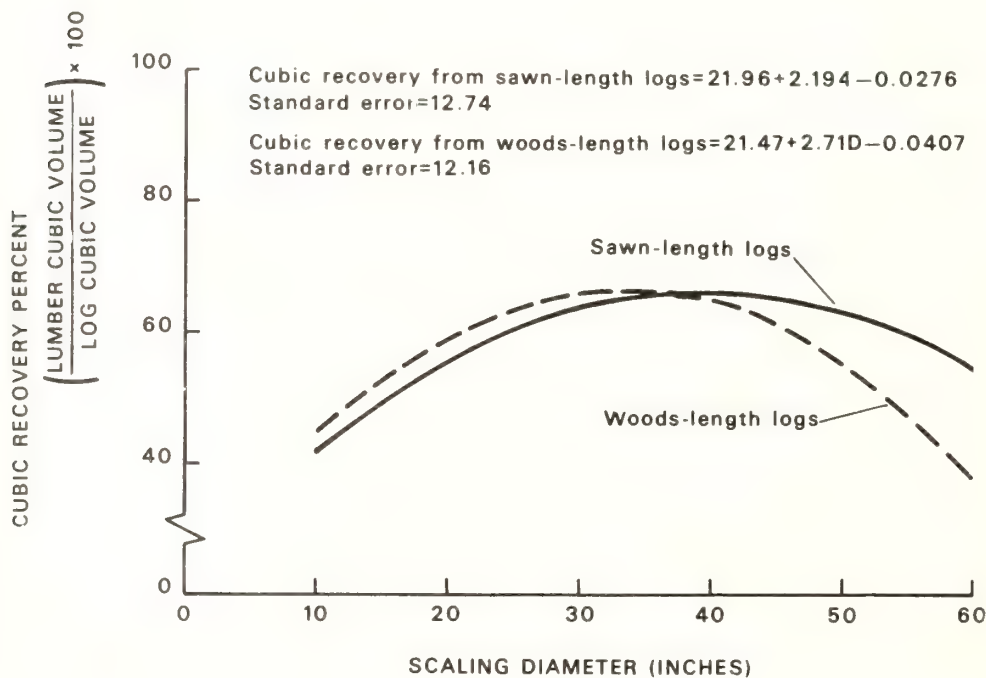


Figure 6.--Relationship of lumber cubic volume recovery percent to scaling diameter.

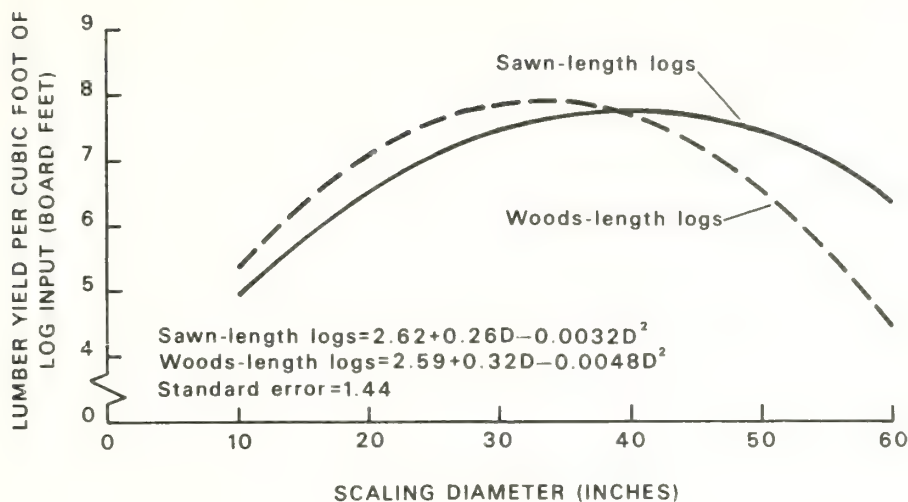


Figure 7.--Relationship of board-foot yield per cubic foot of log input to scaling diameter.

TABLE 7.--Comparison of some average results from two studies of lumber recovery from Coast Douglas-fir

| Characteristic and study                                   | Scaling condition |                   |
|------------------------------------------------------------|-------------------|-------------------|
|                                                            | Sawn-length logs  | Woods-length logs |
| Defect percent:                                            |                   |                   |
| Present <sup>1/</sup>                                      | 37.0              | 47.9              |
| PNW-154 <sup>2/</sup>                                      | 13.0              | 14.5              |
| Lumber recovery percent:                                   |                   |                   |
| Present                                                    | 150.0             | 220.0             |
| PNW-154                                                    | 117.0             | 133.0             |
| Cubic recovery percent:                                    |                   |                   |
| Present                                                    | 62.0              | 62.0              |
| PNW-154                                                    | 64.0              | 63.0              |
| Recovery factor (board feet per cubic foot): <sup>3/</sup> |                   |                   |
| Present                                                    | 7.4               | 7.3               |
| PNW-154                                                    | 7.4               | 7.4               |
| Percent Selects:                                           |                   |                   |
| Present                                                    | 7.1               | 6.7               |
| PNW-154                                                    | 19.5              | 19.5              |
| Percent No. 3 and Economy:                                 |                   |                   |
| Present                                                    | 74.1              | 74.9              |
| PNW-154                                                    | 19.0              | 18.8              |

<sup>1/</sup> Study reported in this paper.

<sup>2/</sup> USDA Forest Service Research Paper PNW-154 (Lane et al. 1973).

<sup>3/</sup> Recovery factor = board feet of lumber yield per cubic foot of log input.



As shown in table 7, the cubic recovery percent and recovery factor for both studies are almost the same, but the percent of lumber yield by grade was noticeably different. Lumber yield from this study contained 7.1 percent Selects versus 19.5 percent reported in PNW-154 (Lane et al. 1973), and the percent No. 3 and Economy was 74.1 percent for this study versus 19.0 percent for PNW-154. These comparisons are more understandable when the difference in defect between the studies is noted

along with the log grade mix. This study had only No. 2 and No. 3 Sawmill logs, but 17 percent of the logs in PNW-154 were of a higher grade.

It is evident from the comparison of these two studies that the additional information was needed to describe the utilization potential of the low-grade, defective portion of the Douglas-fir timber resource.

## Literature Cited

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1973. Lumber recovery from old-growth Coast Douglas-fir. USDA For. Serv. Res. Pap. PNW-154, 44 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.
- West Coast Lumber Inspection Bureau.  
1970. Standard grading and dressing rules for Douglas-fir lumber. No. 16, 213 p. Portland, Oreg.

## Appendix

Tables 8 - 17

TABLE 8.--Log scale, lumber tally, and cubic volume by scaling diameter for No. 2 Sawmill  
sawn-length Coast Douglas-fir logs

| Log scaling diameter (inches) | Number of logs | Log scale <sup>1/</sup> |        | Lumber tally  |                              | Cubic volume     |          |                                     |          |                     |  |
|-------------------------------|----------------|-------------------------|--------|---------------|------------------------------|------------------|----------|-------------------------------------|----------|---------------------|--|
|                               |                | Gross                   | Net    | Volume        | Recovery ratio <sup>2/</sup> | Log              | Lumber   | Lumber recovery ratio <sup>3/</sup> | Sawdust  | Residue             |  |
|                               |                | -- -- Board feet        |        | -- -- Percent |                              | -- -- Cubic feet |          | -- -- Percent                       |          | -- -- Cubic feet -- |  |
| 13                            | 1              | 70                      | 60     | 53            | 88                           | 12.89            | 4.57     | 35                                  | 0.60     | 7.72                |  |
| 14                            | 1              | 140                     | 130    | 173           | 133                          | 26.45            | 14.48    | 55                                  | 2.54     | 9.43                |  |
| 15                            | 1              | 230                     | 170    | 286           | 168                          | 35.16            | 23.73    | 67                                  | 3.77     | 7.66                |  |
| 16                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 17                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 18                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 19                            | 1              | 270                     | 240    | 344           | 143                          | 39.37            | 29.07    | 74                                  | 2.51     | 7.79                |  |
| 20                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 21                            | 1              | 470                     | 240    | 534           | 222                          | 61.02            | 44.95    | 74                                  | 5.29     | 10.78               |  |
| 22                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 23                            | 1              | 600                     | 490    | 635           | 130                          | 78.77            | 53.00    | 67                                  | 6.60     | 19.17               |  |
| 24                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 25                            | 2              | 1,450                   | 1,040  | 925           | 89                           | 180.17           | 77.46    | 43                                  | 12.56    | 90.15               |  |
| 26                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 27                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 28                            | 3              | 2,760                   | 2,170  | 2,564         | 118                          | 339.89           | 214.45   | 63                                  | 30.55    | 94.89               |  |
| 29                            | 2              | 1,780                   | 1,350  | 1,737         | 129                          | 220.00           | 145.31   | 66                                  | 21.70    | 52.99               |  |
| 30                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 31                            | 1              | 1,230                   | 620    | 976           | 157                          | 165.21           | 81.32    | 49                                  | 12.73    | 71.16               |  |
| 32                            | 3              | 2,330                   | 1,630  | 2,681         | 164                          | 305.38           | 225.06   | 74                                  | 32.53    | 47.79               |  |
| 33                            | 1              | 1,250                   | 530    | 571           | 108                          | 156.10           | 48.39    | 31                                  | 7.19     | 100.52              |  |
| 34                            | 1              | 1,160                   | 1,000  | 1,328         | 133                          | 147.11           | 111.70   | 76                                  | 14.51    | 20.90               |  |
| 35                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 36                            | 3              | 4,240                   | 2,840  | 4,127         | 145                          | 531.87           | 347.41   | 65                                  | 41.45    | 143.01              |  |
| 37                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 38                            | 2              | 3,110                   | 1,720  | 3,373         | 196                          | 394.44           | 283.08   | 72                                  | 40.34    | 71.02               |  |
| 39                            | 2              | 3,600                   | 2,910  | 3,282         | 113                          | 435.11           | 274.01   | 63                                  | 42.82    | 118.28              |  |
| 40                            | 1              | 900                     | 400    | 882           | 220                          | 110.09           | 75.59    | 69                                  | 9.63     | 24.87               |  |
| 41                            | 4              | 7,100                   | 3,750  | 6,328         | 169                          | 868.71           | 535.65   | 62                                  | 71.90    | 261.16              |  |
| 42                            | 1              | 1,510                   | 1,050  | 1,396         | 133                          | 185.99           | 119.06   | 64                                  | 15.92    | 51.01               |  |
| 43                            | 3              | 4,880                   | 2,500  | 5,146         | 206                          | 605.52           | 435.49   | 72                                  | 60.36    | 109.67              |  |
| 44                            | 2              | 3,780                   | 2,400  | 3,788         | 158                          | 447.58           | 319.62   | 71                                  | 48.78    | 79.18               |  |
| 45                            | 5              | 10,320                  | 5,420  | 11,291        | 208                          | 1,240.50         | 957.61   | 77                                  | 110.84   | 172.05              |  |
| 46                            | 2              | 2,780                   | 1,710  | 2,537         | 148                          | 337.50           | 215.38   | 64                                  | 31.01    | 91.11               |  |
| 47                            | 2              | 4,460                   | 2,700  | 5,302         | 196                          | 544.86           | 448.01   | 82                                  | 55.15    | 41.70               |  |
| 48                            | 2              | 4,100                   | 2,300  | 3,886         | 169                          | 513.91           | 330.00   | 64                                  | 46.91    | 137.00              |  |
| 49                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 50                            | 1              | 2,110                   | 1,190  | 1,158         | 97                           | 260.60           | 96.76    | 37                                  | 15.43    | 148.41              |  |
| 51                            | 1              | 3,330                   | 1,940  | 3,376         | 174                          | 398.91           | 283.59   | 71                                  | 37.82    | 77.50               |  |
| 52                            | 1              | 2,280                   | 1,220  | 1,113         | 91                           | 275.87           | 93.56    | 34                                  | 14.41    | 167.90              |  |
| 53                            | 1              | 1,840                   | 970    | 1,857         | 191                          | 226.97           | 157.99   | 70                                  | 19.40    | 49.58               |  |
| 54                            | 2              | 5,190                   | 2,310  | 5,028         | 218                          | 627.88           | 429.03   | 68                                  | 51.43    | 147.42              |  |
| 55                            | 4              | 9,340                   | 6,120  | 7,903         | 129                          | 1,152.75         | 668.81   | 58                                  | 87.69    | 396.25              |  |
| 56                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 57                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 58                            | 1              | 3,150                   | 1,740  | 2,003         | 115                          | 386.43           | 168.38   | 44                                  | 25.81    | 192.24              |  |
| 59                            | 1              | 3,730                   | 1,630  | 2,805         | 172                          | 439.47           | 239.84   | 55                                  | 25.41    | 174.22              |  |
| 60                            | 1              | 3,790                   | 3,150  | 4,132         | 131                          | 446.61           | 350.36   | 78                                  | 30.62    | 65.63               |  |
| 61                            | 0              | --                      | --     | --            | --                           | --               | --       | --                                  | --       | --                  |  |
| 62                            | 1              | 3,250                   | 2,030  | 2,671         | 132                          | 389.75           | 225.06   | 58                                  | 34.40    | 130.29              |  |
| Total or average              | 62             | 102,500                 | 61,670 | 96,191        | 156                          | 12,588.84        | 8,127.78 | 65                                  | 1,070.61 | 3,390.45            |  |

<sup>1/</sup> As scaled by Bureau of Land Management scaler by east-side log scaling rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

<sup>3/</sup> Lumber cubic volume as percentage of log cubic volume.

TABLE 9.--Log scale, lumber tally, and cubic volume by scaling diameter for 100-foot  
sawn-length Coast Douglas-fir logs

| Log<br>scaling<br>diameter<br>(inches) | Number<br>of<br>logs | Log scale <sup>1/</sup> |         | Lumber tally |                                 | Cubic volume           |           |                                           |                        |          |
|----------------------------------------|----------------------|-------------------------|---------|--------------|---------------------------------|------------------------|-----------|-------------------------------------------|------------------------|----------|
|                                        |                      | Gross                   | Net     | Volume       | Recovery<br>ratio <sup>2/</sup> | Log                    | Lumber    | Lumber<br>recovery<br>ratio <sup>3/</sup> | Sawdust                | Residue  |
|                                        |                      | -- -- Board feet -- --  |         | Percent      |                                 | -- -- Cubic feet -- -- |           | Percent                                   | -- -- Cubic feet -- -- |          |
| 10                                     | 2                    | 320                     | 190     | 423          | 223                             | 72.25                  | 35.60     | 49                                        | 5.08                   | 31.57    |
| 11                                     | 3                    | 260                     | 210     | 342          | 163                             | 55.60                  | 28.84     | 52                                        | 4.95                   | 21.81    |
| 12                                     | 2                    | 370                     | 260     | 395          | 152                             | 68.87                  | 32.98     | 48                                        | 4.90                   | 30.99    |
| 13                                     | 1                    | 110                     | 110     | 84           | 76                              | 26.02                  | 7.04      | 27                                        | 1.19                   | 17.79    |
| 14                                     | 2                    | 330                     | 220     | 278          | 126                             | 56.74                  | 23.63     | 42                                        | 2.41                   | 30.70    |
| 15                                     | 4                    | 940                     | 660     | 973          | 147                             | 160.89                 | 82.47     | 51                                        | 7.76                   | 70.66    |
| 16                                     | 1                    | 280                     | 280     | 320          | 114                             | 41.82                  | 26.87     | 64                                        | 2.90                   | 12.05    |
| 17                                     | 4                    | 1,240                   | 720     | 1,301        | 181                             | 190.82                 | 109.67    | 57                                        | 13.57                  | 67.58    |
| 18                                     | 4                    | 720                     | 550     | 628          | 114                             | 117.51                 | 52.90     | 45                                        | 7.03                   | 57.58    |
| 19                                     | 7                    | 2,110                   | 1,530   | 2,144        | 140                             | 340.90                 | 180.73    | 53                                        | 21.88                  | 138.29   |
| 20                                     | 3                    | 720                     | 570     | 722          | 127                             | 123.54                 | 60.32     | 49                                        | 7.97                   | 55.25    |
| 21                                     | 3                    | 1,440                   | 850     | 1,399        | 165                             | 220.95                 | 118.16    | 53                                        | 15.67                  | 87.12    |
| 22                                     | 8                    | 4,120                   | 2,870   | 3,714        | 129                             | 586.97                 | 311.77    | 53                                        | 40.44                  | 234.76   |
| 23                                     | 3                    | 2,000                   | 1,230   | 1,688        | 137                             | 290.26                 | 141.87    | 49                                        | 18.67                  | 129.72   |
| 24                                     | 8                    | 4,930                   | 2,930   | 5,294        | 181                             | 730.69                 | 444.05    | 61                                        | 59.61                  | 227.03   |
| 25                                     | 4                    | 1,990                   | 1,360   | 1,773        | 130                             | 264.21                 | 148.44    | 56                                        | 20.40                  | 95.37    |
| 26                                     | 6                    | 4,250                   | 2,640   | 4,237        | 160                             | 593.11                 | 357.71    | 60                                        | 45.35                  | 190.05   |
| 27                                     | 3                    | 1,990                   | 1,410   | 1,782        | 126                             | 284.12                 | 149.65    | 53                                        | 21.15                  | 113.32   |
| 28                                     | 5                    | 4,870                   | 3,380   | 4,039        | 119                             | 653.63                 | 338.94    | 52                                        | 50.45                  | 264.24   |
| 29                                     | 4                    | 3,740                   | 3,160   | 4,116        | 130                             | 493.42                 | 344.12    | 70                                        | 49.67                  | 99.63    |
| 30                                     | 4                    | 3,370                   | 2,170   | 3,653        | 168                             | 464.25                 | 308.91    | 67                                        | 34.34                  | 121.00   |
| 31                                     | 8                    | 8,270                   | 5,330   | 8,492        | 159                             | 1,136.45               | 717.64    | 63                                        | 82.66                  | 336.15   |
| 32                                     | 8                    | 8,420                   | 5,380   | 9,320        | 173                             | 1,130.89               | 787.61    | 70                                        | 87.27                  | 256.01   |
| 33                                     | 2                    | 2,570                   | 2,060   | 2,810        | 136                             | 341.99                 | 236.00    | 69                                        | 29.37                  | 76.62    |
| 34                                     | 4                    | 3,800                   | 2,850   | 4,237        | 149                             | 551.81                 | 355.74    | 64                                        | 48.74                  | 147.33   |
| 35                                     | 0                    | --                      | --      | --           | --                              | --                     | --        | --                                        | --                     | --       |
| 36                                     | 5                    | 6,480                   | 3,650   | 6,684        | 183                             | 890.23                 | 567.33    | 64                                        | 71.03                  | 251.87   |
| 37                                     | 9                    | 13,420                  | 9,290   | 14,498       | 156                             | 1,722.51               | 1,220.55  | 71                                        | 135.74                 | 366.22   |
| 38                                     | 3                    | 5,050                   | 3,070   | 5,118        | 167                             | 660.87                 | 428.93    | 65                                        | 52.54                  | 179.40   |
| 39                                     | 3                    | 5,120                   | 3,110   | 4,802        | 154                             | 655.24                 | 406.02    | 62                                        | 49.87                  | 199.35   |
| 40                                     | 2                    | 3,000                   | 2,270   | 2,547        | 112                             | 371.81                 | 215.67    | 58                                        | 28.87                  | 127.27   |
| 41                                     | 5                    | 9,190                   | 6,460   | 9,008        | 139                             | 1,142.24               | 764.41    | 67                                        | 70.21                  | 307.62   |
| 42                                     | 3                    | 6,000                   | 4,490   | 6,217        | 138                             | 732.42                 | 523.10    | 71                                        | 75.99                  | 133.33   |
| 43                                     | 2                    | 3,480                   | 1,880   | 2,573        | 137                             | 427.77                 | 217.77    | 51                                        | 29.83                  | 180.17   |
| 44                                     | 4                    | 7,250                   | 4,770   | 6,007        | 126                             | 869.62                 | 503.46    | 58                                        | 74.57                  | 291.59   |
| 45                                     | 2                    | 4,540                   | 2,520   | 4,410        | 175                             | 562.79                 | 373.01    | 66                                        | 47.76                  | 141.93   |
| 46                                     | 7                    | 17,170                  | 10,860  | 16,391       | 151                             | 2,118.89               | 1,371.15  | 65                                        | 172.42                 | 575.32   |
| 47                                     | 3                    | 6,960                   | 5,170   | 5,807        | 112                             | 876.07                 | 486.63    | 56                                        | 70.96                  | 318.48   |
| 48                                     | 1                    | 2,700                   | 1,860   | 1,962        | 105                             | 327.77                 | 164.07    | 50                                        | 25.88                  | 137.82   |
| 49                                     | 1                    | 1,570                   | 1,050   | 1,445        | 138                             | 194.90                 | 120.45    | 62                                        | 18.32                  | 56.13    |
| 50                                     | 1                    | 2,110                   | 1,510   | 2,201        | 146                             | 260.60                 | 185.52    | 71                                        | 22.16                  | 52.92    |
| 51                                     | 0                    | --                      | --      | --           | --                              | --                     | --        | --                                        | --                     | --       |
| 52                                     | 2                    | 5,710                   | 2,700   | 3,965        | 147                             | 695.30                 | 338.24    | 49                                        | 39.15                  | 317.91   |
| 53                                     | 2                    | 4,860                   | 2,990   | 4,448        | 145                             | 579.41                 | 372.96    | 64                                        | 49.82                  | 156.63   |
| 54                                     | 1                    | 2,180                   | 1,120   | 1,381        | 123                             | 264.07                 | 114.85    | 43                                        | 15.57                  | 133.65   |
| 55                                     | 1                    | 2,830                   | 1,590   | 1,998        | 126                             | 348.47                 | 167.78    | 48                                        | 26.66                  | 154.03   |
| 56                                     | 1                    | 2,350                   | 970     | 1,764        | 182                             | 283.62                 | 147.04    | 52                                        | 19.66                  | 116.92   |
| Total or<br>average                    | 161                  | 175,130                 | 114,250 | 167,390      | 147                             | 22,982.22              | 14,090.60 | 61                                        | 1,780.44               | 7,111.18 |

<sup>1/</sup> As scaled by Bureau of Land Management scaler by east-side log scaling rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

<sup>3/</sup> Lumber cubic volume as percentage of log cubic volume.

TABLE 10.--Log scale, lumber tally, and cubic volume by scaling diameter for all log grades of sawn-length Coast Douglas-fir logs

| Log scaling diameter (inches) | Number of logs | Log scale <sup>1/</sup> |         | Lumber tally |                              | Cubic volume |           |                                     |            |           |
|-------------------------------|----------------|-------------------------|---------|--------------|------------------------------|--------------|-----------|-------------------------------------|------------|-----------|
|                               |                | Gross                   | Net     | Volume       | Recovery ratio <sup>2/</sup> | Log          | Lumber    | Lumber recovery ratio <sup>3/</sup> | Sawdust    | Residue   |
|                               |                | Board feet              |         | Percent      |                              | Cubic feet   |           | Percent                             | Cubic feet |           |
| 10                            | 2              | 320                     | 190     | 423          | 223                          | 72.25        | 35.60     | 49                                  | 5.08       | 31.57     |
| 11                            | 3              | 260                     | 210     | 342          | 163                          | 55.60        | 28.84     | 52                                  | 4.95       | 21.81     |
| 12                            | 2              | 370                     | 260     | 395          | 152                          | 68.87        | 32.98     | 48                                  | 4.90       | 30.99     |
| 13                            | 2              | 180                     | 170     | 137          | 81                           | 38.91        | 11.61     | 30                                  | 1.79       | 25.51     |
| 14                            | 3              | 470                     | 350     | 451          | 129                          | 83.19        | 38.11     | 46                                  | 4.95       | 40.13     |
| 15                            | 5              | 1,170                   | 830     | 1,259        | 152                          | 196.05       | 106.20    | 54                                  | 11.53      | 78.32     |
| 16                            | 1              | 280                     | 280     | 320          | 114                          | 41.82        | 26.87     | 64                                  | 2.90       | 12.05     |
| 17                            | 4              | 1,240                   | 720     | 1,301        | 181                          | 190.82       | 109.67    | 57                                  | 13.57      | 67.58     |
| 18                            | 4              | 720                     | 550     | 628          | 114                          | 117.51       | 52.90     | 45                                  | 7.03       | 57.58     |
| 19                            | 8              | 2,380                   | 1,770   | 2,488        | 141                          | 380.27       | 209.80    | 55                                  | 24.39      | 146.08    |
| 20                            | 3              | 720                     | 570     | 722          | 127                          | 123.54       | 60.32     | 49                                  | 7.97       | 55.25     |
| 21                            | 4              | 1,910                   | 1,090   | 1,933        | 177                          | 281.97       | 163.11    | 58                                  | 20.96      | 97.90     |
| 22                            | 8              | 4,120                   | 2,870   | 3,714        | 129                          | 586.97       | 311.77    | 53                                  | 40.44      | 234.76    |
| 23                            | 4              | 2,600                   | 1,720   | 2,323        | 135                          | 369.03       | 194.87    | 53                                  | 25.27      | 148.89    |
| 24                            | 8              | 4,930                   | 2,930   | 5,294        | 181                          | 730.69       | 444.05    | 61                                  | 59.61      | 227.03    |
| 25                            | 6              | 3,440                   | 2,400   | 2,698        | 112                          | 444.38       | 225.90    | 51                                  | 32.96      | 185.52    |
| 26                            | 6              | 4,250                   | 2,640   | 4,237        | 160                          | 593.11       | 357.71    | 60                                  | 45.35      | 190.05    |
| 27                            | 3              | 1,990                   | 1,410   | 1,782        | 126                          | 284.12       | 149.65    | 53                                  | 21.15      | 113.32    |
| 28                            | 8              | 7,630                   | 5,550   | 6,603        | 119                          | 993.52       | 553.39    | 56                                  | 81.00      | 359.13    |
| 29                            | 6              | 5,520                   | 4,510   | 5,853        | 130                          | 713.42       | 489.43    | 69                                  | 71.37      | 152.62    |
| 30                            | 4              | 3,370                   | 2,170   | 3,653        | 168                          | 464.25       | 308.91    | 67                                  | 34.34      | 121.00    |
| 31                            | 9              | 9,500                   | 5,950   | 9,468        | 159                          | 1,301.66     | 798.96    | 61                                  | 95.39      | 407.31    |
| 32                            | 11             | 10,750                  | 7,010   | 12,001       | 171                          | 1,436.27     | 1,012.67  | 71                                  | 119.80     | 303.80    |
| 33                            | 3              | 3,820                   | 2,590   | 3,381        | 131                          | 498.09       | 284.39    | 57                                  | 36.56      | 177.14    |
| 34                            | 5              | 4,960                   | 3,850   | 5,565        | 145                          | 698.92       | 467.44    | 67                                  | 63.25      | 168.23    |
| 35                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 36                            | 8              | 10,720                  | 6,490   | 10,811       | 167                          | 1,422.10     | 914.74    | 64                                  | 112.48     | 394.88    |
| 37                            | 9              | 13,420                  | 9,290   | 14,498       | 156                          | 1,722.51     | 1,220.55  | 71                                  | 135.74     | 366.22    |
| 38                            | 5              | 8,160                   | 4,790   | 8,491        | 177                          | 1,055.31     | 712.01    | 67                                  | 92.88      | 250.42    |
| 39                            | 5              | 8,720                   | 6,020   | 8,084        | 134                          | 1,090.35     | 680.03    | 62                                  | 92.69      | 317.63    |
| 40                            | 3              | 3,900                   | 2,670   | 3,429        | 128                          | 481.90       | 291.26    | 60                                  | 38.50      | 152.14    |
| 41                            | 9              | 16,290                  | 10,210  | 15,336       | 150                          | 2,010.95     | 1,300.06  | 65                                  | 142.11     | 568.78    |
| 42                            | 4              | 7,510                   | 5,540   | 7,613        | 137                          | 918.41       | 642.16    | 70                                  | 91.91      | 184.34    |
| 43                            | 5              | 8,360                   | 4,380   | 7,719        | 176                          | 1,033.29     | 653.26    | 63                                  | 90.19      | 289.84    |
| 44                            | 6              | 11,030                  | 7,170   | 9,795        | 137                          | 1,317.20     | 823.08    | 62                                  | 123.35     | 370.77    |
| 45                            | 7              | 14,860                  | 7,940   | 15,701       | 198                          | 1,803.20     | 1,330.62  | 74                                  | 158.60     | 313.98    |
| 46                            | 9              | 19,950                  | 12,570  | 18,928       | 151                          | 2,456.39     | 1,586.53  | 65                                  | 203.43     | 666.43    |
| 47                            | 5              | 11,420                  | 7,870   | 11,109       | 141                          | 1,420.93     | 934.64    | 66                                  | 126.11     | 360.18    |
| 48                            | 3              | 6,800                   | 4,160   | 5,848        | 141                          | 841.68       | 494.07    | 59                                  | 72.79      | 274.82    |
| 49                            | 1              | 1,570                   | 1,050   | 1,445        | 138                          | 194.90       | 120.45    | 62                                  | 18.32      | 56.13     |
| 50                            | 2              | 4,220                   | 2,700   | 3,359        | 124                          | 521.20       | 282.28    | 54                                  | 37.59      | 201.33    |
| 51                            | 1              | 3,300                   | 1,940   | 3,376        | 174                          | 398.91       | 283.59    | 71                                  | 37.82      | 77.50     |
| 52                            | 3              | 7,990                   | 3,920   | 5,078        | 130                          | 971.17       | 431.80    | 44                                  | 53.56      | 485.81    |
| 53                            | 3              | 6,700                   | 3,960   | 6,305        | 159                          | 806.38       | 530.95    | 66                                  | 69.22      | 206.21    |
| 54                            | 3              | 7,370                   | 3,430   | 6,409        | 187                          | 891.95       | 543.88    | 61                                  | 67.00      | 281.07    |
| 55                            | 5              | 12,170                  | 7,710   | 9,901        | 128                          | 1,501.22     | 836.59    | 56                                  | 114.35     | 550.28    |
| 56                            | 1              | 2,350                   | 970     | 1,764        | 182                          | 283.62       | 147.04    | 52                                  | 19.66      | 116.92    |
| 57                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 58                            | 1              | 3,150                   | 1,740   | 2,003        | 115                          | 386.43       | 168.38    | 44                                  | 25.81      | 192.24    |
| 59                            | 1              | 3,730                   | 1,630   | 2,805        | 172                          | 439.47       | 239.84    | 55                                  | 25.41      | 174.22    |
| 60                            | 1              | 3,790                   | 3,150   | 4,132        | 131                          | 446.61       | 350.36    | 78                                  | 30.62      | 65.63     |
| 61                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 62                            | 1              | 3,250                   | 2,030   | 2,671        | 132                          | 389.75       | 225.06    | 58                                  | 34.40      | 130.29    |
| Total or average              | 223            | 277,630                 | 175,920 | 263,581      | 150                          | 35,571.06    | 22,218.38 | 62                                  | 2,851.05   | 10,501.63 |

<sup>1/</sup> As scaled by Bureau of Land Management scaler by east-side log scaling rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

<sup>3/</sup> Lumber cubic volume as percentage of log cubic volume.



TABLE 11.--Log scaling, lumber tally, and cubic volume of Douglas-fir logs from the  
woods-length Coast Douglas-fir logs

| Log scaling diameter (inches) | Number of logs | Log scale <sup>1/</sup> |        | Lumber tally |                              | Cubic volume |          |                                     |            |          |
|-------------------------------|----------------|-------------------------|--------|--------------|------------------------------|--------------|----------|-------------------------------------|------------|----------|
|                               |                | Gross                   | Net    | Volume       | Recovery ratio <sup>2/</sup> | Log          | Lumber   | Lumber recovery ratio <sup>3/</sup> | Sawdust    | Residue  |
|                               |                | Board feet              |        | Percent      |                              | Cubic feet   |          | Percent                             | Cubic feet |          |
| 14                            | 1              | 1,600                   | 1,100  | 178          | 16                           | 39.52        | 14.82    | 38                                  | 2.41       | 22.29    |
| 15                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 16                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 17                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 18                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 19                            | 1              | 600                     | 210    | 878          | 418                          | 101.30       | 74.02    | 73                                  | 7.80       | 19.48    |
| 20                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 21                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 22                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 23                            | 1              | 1,150                   | 900    | 1,322        | 147                          | 156.55       | 110.45   | 71                                  | 14.01      | 32.09    |
| 24                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 25                            | 2              | 2,530                   | 1,400  | 3,248        | 232                          | 394.02       | 273.21   | 69                                  | 39.18      | 81.63    |
| 26                            | 1              | 1,030                   | 440    | 700          | 159                          | 142.70       | 59.48    | 42                                  | 6.95       | 76.27    |
| 27                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 28                            | 1              | 1,460                   | 1,250  | 1,833        | 147                          | 231.91       | 152.71   | 66                                  | 23.43      | 55.77    |
| 29                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 30                            | 1              | 2,090                   | 1,400  | 2,811        | 201                          | 313.37       | 238.16   | 76                                  | 27.68      | 47.53    |
| 31                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 32                            | 2              | 2,070                   | 1,010  | 2,343        | 232                          | 277.74       | 195.54   | 70                                  | 24.97      | 57.23    |
| 33                            | 1              | 1,960                   | 980    | 1,820        | 186                          | 299.83       | 153.22   | 51                                  | 23.84      | 122.77   |
| 34                            | 2              | 4,740                   | 4,290  | 6,021        | 140                          | 696.27       | 504.21   | 72                                  | 71.27      | 120.79   |
| 35                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 36                            | 2              | 4,600                   | 2,020  | 6,225        | 308                          | 807.00       | 526.54   | 65                                  | 68.13      | 212.33   |
| 37                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 38                            | 2              | 6,260                   | 4,140  | 6,828        | 165                          | 1,026.48     | 579.80   | 56                                  | 68.55      | 378.13   |
| 39                            | 1              | 3,590                   | 2,110  | 4,616        | 219                          | 596.99       | 387.94   | 65                                  | 57.74      | 151.31   |
| 40                            | 3              | 9,170                   | 5,260  | 10,826       | 206                          | 1,368.78     | 913.20   | 67                                  | 114.55     | 341.03   |
| 41                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 42                            | 2              | 5,040                   | 2,070  | 4,188        | 202                          | 704.97       | 351.20   | 50                                  | 51.36      | 302.41   |
| 43                            | 1              | 3,480                   | 1,220  | 3,936        | 323                          | 515.38       | 331.24   | 64                                  | 43.35      | 140.79   |
| 44                            | 2              | 7,400                   | 2,950  | 7,530        | 255                          | 1,084.79     | 636.63   | 59                                  | 83.03      | 365.13   |
| 45                            | 3              | 11,210                  | 5,410  | 12,050       | 223                          | 1,518.39     | 1,016.99 | 67                                  | 142.97     | 358.43   |
| 46                            | 2              | 7,920                   | 3,610  | 8,022        | 222                          | 1,162.97     | 675.83   | 58                                  | 88.94      | 398.20   |
| 47                            | 1              | 4,140                   | 2,070  | 4,847        | 234                          | 603.52       | 400.60   | 66                                  | 49.28      | 153.64   |
| 48                            | 1              | 4,320                   | 1,510  | 3,519        | 233                          | 614.65       | 296.14   | 48                                  | 39.77      | 278.74   |
| 49                            | 1              | 4,490                   | 1,570  | 4,748        | 302                          | 739.80       | 402.11   | 54                                  | 49.71      | 287.98   |
| 50                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 51                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 52                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 53                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 54                            | 1              | 5,460                   | 2,180  | 4,001        | 184                          | 815.36       | 336.16   | 41                                  | 52.47      | 426.73   |
| 55                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 56                            | 0              | --                      | --     | --           | --                           | --           | --       | --                                  | --         | --       |
| 57                            | 1              | 6,090                   | 4,700  | 6,803        | 145                          | 941.24       | 575.42   | 61                                  | 65.02      | 300.80   |
| Total or average              | 36             | 102,400                 | 53,800 | 109,293      | 203                          | 15,153.53    | 9,205.62 | 61                                  | 1,216.41   | 4,731.50 |

<sup>1/</sup> As scaled by Forest Service scaler by west-side log scaling rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

<sup>3/</sup> Lumber cubic volume as percentage of log cubic volume.

TABLE 12.--Log scale, lumber tally, and cubic volume by scaling diameter for No. 3 Sawmill  
woods-length Coast Douglas-fir logs

| Log<br>scaling<br>diameter<br>(inches) | Number<br>of<br>logs | Log scale <sup>1/</sup> |        | Lumber tally |                                 | Cubic volume |           |                                           |            |          |
|----------------------------------------|----------------------|-------------------------|--------|--------------|---------------------------------|--------------|-----------|-------------------------------------------|------------|----------|
|                                        |                      | Gross                   | Net    | Volume       | Recovery<br>ratio <sup>2/</sup> | Log          | Lumber    | Lumber<br>recovery<br>ratio <sup>3/</sup> | Sawdust    | Residue  |
|                                        |                      | Board feet              |        | Percent      |                                 | Cubic feet   |           | Percent                                   | Cubic feet |          |
| 10                                     | 2                    | 160                     | 100    | 366          | 366                             | 54.04        | 30.39     | 56                                        | 5.01       | 18.64    |
| 11                                     | 5                    | 740                     | 420    | 1,733        | 413                             | 287.38       | 145.82    | 51                                        | 19.12      | 122.44   |
| 12                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 13                                     | 4                    | 500                     | 380    | 702          | 185                             | 123.67       | 59.32     | 48                                        | 7.09       | 57.26    |
| 14                                     | 3                    | 810                     | 490    | 1,370        | 280                             | 225.19       | 115.60    | 51                                        | 12.40      | 97.19    |
| 15                                     | 3                    | 680                     | 350    | 794          | 227                             | 134.57       | 66.32     | 49                                        | 9.79       | 58.46    |
| 16                                     | 2                    | 560                     | 330    | 655          | 198                             | 120.50       | 54.57     | 45                                        | 8.27       | 57.66    |
| 17                                     | 2                    | 1,250                   | 740    | 1,782        | 241                             | 273.25       | 149.91    | 55                                        | 23.34      | 100.00   |
| 18                                     | 6                    | 1,920                   | 1,190  | 2,494        | 210                             | 387.67       | 211.06    | 54                                        | 26.69      | 149.92   |
| 19                                     | 3                    | 1,200                   | 780    | 1,976        | 253                             | 240.98       | 166.43    | 69                                        | 17.19      | 57.36    |
| 20                                     | 3                    | 1,350                   | 690    | 1,734        | 251                             | 253.67       | 145.88    | 58                                        | 21.02      | 86.77    |
| 21                                     | 2                    | 1,790                   | 1,190  | 2,841        | 239                             | 368.60       | 238.59    | 65                                        | 31.24      | 98.77    |
| 22                                     | 4                    | 3,300                   | 2,320  | 4,787        | 206                             | 653.92       | 402.93    | 62                                        | 47.49      | 203.50   |
| 23                                     | 2                    | 1,850                   | 850    | 3,040        | 358                             | 388.48       | 253.71    | 65                                        | 35.41      | 99.36    |
| 24                                     | 3                    | 3,020                   | 2,450  | 4,488        | 183                             | 512.25       | 377.90    | 74                                        | 46.32      | 88.03    |
| 25                                     | 1                    | 1,380                   | 1,050  | 1,762        | 168                             | 249.66       | 148.13    | 59                                        | 20.30      | 81.23    |
| 26                                     | 2                    | 2,360                   | 980    | 3,247        | 331                             | 399.13       | 274.22    | 69                                        | 29.39      | 95.52    |
| 27                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 28                                     | 2                    | 2,880                   | 1,370  | 3,369        | 246                             | 424.93       | 280.92    | 66                                        | 42.41      | 101.60   |
| 29                                     | 2                    | 2,550                   | 1,210  | 2,928        | 242                             | 382.57       | 245.88    | 64                                        | 37.99      | 98.70    |
| 30                                     | 1                    | 1,640                   | 600    | 1,992        | 332                             | 319.69       | 166.37    | 52                                        | 25.89      | 127.43   |
| 31                                     | 3                    | 5,000                   | 2,490  | 7,210        | 290                             | 792.12       | 608.26    | 77                                        | 65.54      | 118.32   |
| 32                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 33                                     | 3                    | 6,410                   | 3,860  | 9,073        | 235                             | 1,101.95     | 764.42    | 69                                        | 93.10      | 244.43   |
| 34                                     | 2                    | 4,000                   | 1,590  | 4,809        | 302                             | 679.15       | 407.59    | 60                                        | 48.03      | 223.53   |
| 35                                     | 5                    | 11,030                  | 5,490  | 15,093       | 275                             | 1,849.04     | 1,278.22  | 69                                        | 126.39     | 444.43   |
| 36                                     | 2                    | 4,600                   | 2,230  | 6,654        | 298                             | 746.78       | 559.96    | 75                                        | 66.94      | 119.88   |
| 37                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 38                                     | 4                    | 11,270                  | 4,780  | 14,294       | 299                             | 1,875.91     | 1,198.26  | 64                                        | 164.51     | 513.14   |
| 39                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 40                                     | 1                    | 3,000                   | 1,040  | 2,832        | 272                             | 423.53       | 243.31    | 57                                        | 28.19      | 152.03   |
| 41                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 42                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 43                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 44                                     | 2                    | 8,080                   | 3,910  | 7,886        | 202                             | 1,163.14     | 664.14    | 57                                        | 84.78      | 414.72   |
| 45                                     | 1                    | 3,980                   | 1,590  | 3,568        | 224                             | 645.44       | 304.29    | 47                                        | 33.37      | 307.78   |
| 46                                     | 2                    | 6,140                   | 3,550  | 4,557        | 128                             | 908.29       | 383.76    | 42                                        | 55.68      | 468.85   |
| 47                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 48                                     | 1                    | 4,320                   | 2,160  | 5,329        | 247                             | 638.79       | 446.65    | 70                                        | 56.49      | 135.65   |
| 49                                     | 2                    | 9,190                   | 5,870  | 8,481        | 144                             | 1,243.19     | 712.79    | 57                                        | 97.70      | 432.70   |
| 50                                     | 0                    | --                      | --     | --           | --                              | --           | --        | --                                        | --         | --       |
| 51                                     | 1                    | 4,870                   | 1,700  | 4,818        | 283                             | 648.90       | 411.83    | 63                                        | 42.87      | 194.20   |
| Total or<br>average                    | 81                   | 111,830                 | 57,750 | 136,664      | 237                             | 18,516.88    | 11,517.43 | 62                                        | 1,429.95   | 5,569.50 |

<sup>1/</sup> As scaled by Forest Service scaler by west-side log scaling rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

<sup>3/</sup> Lumber cubic volume as percentage of log cubic volume.

TABLE 13.--Log scale, lumber tally, and cubic volume by scaling diameter and log grades of woods-length Coast Douglas-fir logs

| Log scaling diameter (inches) | Number of logs | Log scale <sup>1/</sup> |         | Lumber tally |                              | Cubic volume |           |                                     |            |           |
|-------------------------------|----------------|-------------------------|---------|--------------|------------------------------|--------------|-----------|-------------------------------------|------------|-----------|
|                               |                | Gross                   | Net     | Volume       | Recovery ratio <sup>2/</sup> | Log          | Lumber    | Lumber recovery ratio <sup>3/</sup> | Sawdust    | Residue   |
|                               |                | Board feet              |         | Percent      |                              | Cubic feet   |           | Percent                             | Cubic feet |           |
| 10                            | 2              | 160                     | 100     | 366          | 366                          | 54.04        | 30.39     | 56                                  | 5.01       | 18.64     |
| 11                            | 5              | 740                     | 420     | 1,733        | 413                          | 287.38       | 145.82    | 51                                  | 19.12      | 122.44    |
| 12                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 13                            | 4              | 500                     | 380     | 702          | 185                          | 123.67       | 59.32     | 48                                  | 7.09       | 57.26     |
| 14                            | 4              | 2,410                   | 1,590   | 1,548        | 97                           | 264.71       | 130.42    | 49                                  | 14.81      | 119.48    |
| 15                            | 3              | 680                     | 350     | 794          | 227                          | 134.57       | 66.32     | 49                                  | 9.79       | 58.46     |
| 16                            | 2              | 560                     | 330     | 655          | 198                          | 120.50       | 54.57     | 45                                  | 8.27       | 57.66     |
| 17                            | 2              | 1,250                   | 740     | 1,782        | 241                          | 273.25       | 149.91    | 55                                  | 23.34      | 100.00    |
| 18                            | 6              | 1,920                   | 1,190   | 2,494        | 210                          | 387.67       | 211.06    | 54                                  | 26.69      | 149.92    |
| 19                            | 4              | 1,800                   | 990     | 2,854        | 288                          | 342.28       | 240.45    | 70                                  | 24.99      | 76.84     |
| 20                            | 3              | 1,350                   | 690     | 1,734        | 251                          | 253.67       | 145.88    | 58                                  | 21.02      | 86.77     |
| 21                            | 2              | 1,790                   | 1,190   | 2,841        | 239                          | 368.60       | 238.59    | 65                                  | 31.24      | 98.77     |
| 22                            | 4              | 3,300                   | 2,320   | 4,787        | 206                          | 653.92       | 402.93    | 62                                  | 47.49      | 203.50    |
| 23                            | 3              | 3,000                   | 1,750   | 4,362        | 249                          | 545.03       | 364.16    | 67                                  | 49.42      | 131.45    |
| 24                            | 3              | 3,020                   | 2,450   | 4,488        | 183                          | 512.25       | 377.90    | 74                                  | 46.32      | 88.03     |
| 25                            | 3              | 3,910                   | 2,450   | 5,010        | 204                          | 643.68       | 421.34    | 65                                  | 59.48      | 162.86    |
| 26                            | 3              | 3,390                   | 1,420   | 3,947        | 278                          | 541.83       | 333.70    | 62                                  | 36.34      | 171.79    |
| 27                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 28                            | 3              | 4,340                   | 2,620   | 5,202        | 199                          | 656.84       | 433.63    | 66                                  | 65.84      | 157.37    |
| 29                            | 2              | 2,550                   | 1,210   | 2,928        | 242                          | 382.57       | 245.88    | 64                                  | 37.99      | 98.70     |
| 30                            | 2              | 3,730                   | 2,000   | 4,803        | 240                          | 633.06       | 404.53    | 64                                  | 53.57      | 174.96    |
| 31                            | 3              | 5,000                   | 2,490   | 7,210        | 290                          | 792.12       | 608.26    | 77                                  | 65.54      | 118.32    |
| 32                            | 2              | 2,070                   | 1,010   | 2,343        | 232                          | 277.74       | 195.54    | 70                                  | 24.97      | 57.23     |
| 33                            | 4              | 8,370                   | 4,840   | 10,893       | 225                          | 1,401.78     | 917.64    | 65                                  | 116.94     | 367.20    |
| 34                            | 4              | 8,740                   | 5,880   | 10,830       | 184                          | 1,375.42     | 911.80    | 66                                  | 119.30     | 344.32    |
| 35                            | 5              | 11,030                  | 5,490   | 15,093       | 275                          | 1,849.04     | 1,278.22  | 69                                  | 126.39     | 444.43    |
| 36                            | 4              | 9,200                   | 4,250   | 12,879       | 303                          | 1,553.78     | 1,086.50  | 70                                  | 135.07     | 332.21    |
| 37                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 38                            | 6              | 17,530                  | 8,920   | 21,122       | 237                          | 2,902.39     | 1,778.06  | 61                                  | 233.06     | 891.27    |
| 39                            | 1              | 3,590                   | 2,110   | 4,616        | 219                          | 596.99       | 387.94    | 65                                  | 57.74      | 151.31    |
| 40                            | 4              | 12,170                  | 6,300   | 13,658       | 217                          | 1,792.31     | 1,156.51  | 65                                  | 142.74     | 493.06    |
| 41                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 42                            | 2              | 5,040                   | 2,070   | 4,188        | 202                          | 704.97       | 351.20    | 50                                  | 51.36      | 302.41    |
| 43                            | 1              | 3,480                   | 1,220   | 3,936        | 323                          | 515.38       | 331.24    | 64                                  | 43.35      | 140.79    |
| 44                            | 4              | 15,480                  | 6,860   | 15,416       | 225                          | 2,248.43     | 1,300.77  | 58                                  | 167.81     | 779.85    |
| 45                            | 4              | 15,190                  | 7,000   | 15,618       | 223                          | 2,163.83     | 1,321.28  | 61                                  | 176.34     | 666.21    |
| 46                            | 4              | 14,060                  | 7,160   | 12,579       | 176                          | 2,071.26     | 1,059.59  | 51                                  | 144.62     | 867.05    |
| 47                            | 1              | 4,140                   | 2,070   | 4,847        | 234                          | 603.52       | 400.60    | 66                                  | 49.28      | 153.64    |
| 48                            | 2              | 8,640                   | 3,670   | 8,848        | 241                          | 1,253.44     | 742.79    | 59                                  | 96.26      | 414.39    |
| 49                            | 3              | 13,680                  | 7,440   | 13,229       | 178                          | 1,982.99     | 1,114.90  | 56                                  | 147.41     | 720.68    |
| 50                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 51                            | 1              | 4,870                   | 1,700   | 4,818        | 283                          | 648.90       | 411.83    | 63                                  | 42.87      | 194.20    |
| 52                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 53                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 54                            | 1              | 5,460                   | 2,180   | 4,001        | 184                          | 815.36       | 336.16    | 41                                  | 52.47      | 426.73    |
| 55                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 56                            | 0              | --                      | --      | --           | --                           | --           | --        | --                                  | --         | --        |
| 57                            | 1              | 6,090                   | 4,700   | 6,803        | 145                          | 941.24       | 575.42    | 61                                  | 65.02      | 300.80    |
| Total or average              | 117            | 214,230                 | 111,550 | 245,957      | 220                          | 33,670.41    | 20,723.05 | 62                                  | 2,646.36   | 10,301.00 |

<sup>1/</sup> As scaled by Forest Service scaler by west-side log scaling rules, Scribner Decimal C log rule.

<sup>2/</sup> Lumber tally volume as percentage of net scale volume.

<sup>3/</sup> Lumber cubic volume as percentage of log cubic volume.

TABLE 14.--Lumber grade yields expressed as a percent of lumber tally volume by scaling diameter, No. 2 Sawmill  
sawn-length Coast Douglas-fir logs

| Log<br>scaling<br>diameter<br>(inches) | Number<br>of<br>logs | Lumber<br>tally<br>volume | Lumber grade           |             |             |                      |                           |                       |                      |         |
|----------------------------------------|----------------------|---------------------------|------------------------|-------------|-------------|----------------------|---------------------------|-----------------------|----------------------|---------|
|                                        |                      |                           | B and Better<br>Select | C<br>Select | D<br>Select | Select<br>Structural | No. 1 and<br>Construction | No. 2 and<br>Standard | No. 3 and<br>Utility | Economy |
| Board feet                             |                      |                           |                        |             |             |                      |                           |                       |                      |         |
| 13                                     | 1                    | 53                        | 0                      | 0           | --          | --                   | 45.28                     | 54.72                 | --                   | --      |
| 14                                     | 1                    | 173                       | 0                      | 0           | 12.14       | --                   | 35.84                     | 15.61                 | 29.48                | 6.94    |
| 15                                     | 1                    | 286                       | --                     | --          | --          | --                   | 5.59                      | 4.55                  | 59.09                | 30.77   |
| 16                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 17                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 18                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 19                                     | 1                    | 344                       | --                     | --          | --          | --                   | 19.19                     | 65.99                 | 14.83                | --      |
| 20                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 21                                     | 1                    | 534                       | --                     | --          | --          | --                   | --                        | --                    | 34.27                | 65.73   |
| 22                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 23                                     | 1                    | 635                       | --                     | .47         | 1.89        | 10.39                | 32.44                     | 25.04                 | 24.88                | 4.88    |
| 24                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 25                                     | 2                    | 925                       | --                     | 23.14       | --          | 3.14                 | 6.81                      | 15.89                 | 17.84                | 33.19   |
| 26                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 27                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 28                                     | 3                    | 2,564                     | --                     | 4.68        | --          | 12.52                | 10.92                     | 35.57                 | 15.56                | 20.75   |
| 29                                     | 2                    | 1,737                     | --                     | 16.00       | .92         | 15.20                | 21.82                     | 15.77                 | 15.43                | 14.85   |
| 30                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 31                                     | 1                    | 976                       | --                     | 24.28       | --          | 33.91                | 9.73                      | 5.12                  | 9.84                 | 17.11   |
| 32                                     | 3                    | 2,681                     | --                     | 6.60        | 4.89        | 3.28                 | 9.62                      | 15.93                 | 35.84                | 23.83   |
| 33                                     | 1                    | 571                       | --                     | 23.47       | --          | --                   | --                        | 5.60                  | 2.10                 | 68.83   |
| 34                                     | 1                    | 1,328                     | --                     | 4.97        | 2.18        | 13.78                | 9.94                      | 43.30                 | 24.55                | 1.28    |
| 35                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 36                                     | 3                    | 4,127                     | --                     | 17.32       | .70         | 8.14                 | 14.30                     | 5.62                  | 19.12                | 34.80   |
| 37                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 38                                     | 2                    | 3,373                     | --                     | 23.27       | 4.24        | 14.23                | 5.60                      | 11.24                 | 19.63                | 21.79   |
| 39                                     | 2                    | 3,282                     | --                     | 3.81        | .21         | .79                  | 1.77                      | 9.66                  | 64.93                | 18.83   |
| 40                                     | 1                    | 882                       | --                     | 12.24       | .91         | --                   | 1.47                      | 1.47                  | 24.60                | 59.30   |
| 41                                     | 4                    | 6,328                     | --                     | 6.13        | .49         | .21                  | 5.89                      | 6.15                  | 30.78                | 50.35   |
| 42                                     | 1                    | 1,396                     | --                     | 58.88       | --          | --                   | 3.15                      | 2.01                  | 14.47                | 21.49   |
| 43                                     | 3                    | 5,146                     | .68                    | 6.18        | 1.42        | --                   | .47                       | .70                   | 14.34                | 76.21   |
| 44                                     | 2                    | 3,788                     | --                     | 36.67       | 5.49        | 1.24                 | 1.16                      | 4.96                  | 7.95                 | 42.53   |
| 45                                     | 5                    | 11,291                    | --                     | 2.41        | 1.20        | 1.75                 | 4.01                      | 7.86                  | 40.66                | 42.10   |
| 46                                     | 2                    | 2,537                     | --                     | 40.20       | 2.01        | 2.56                 | 4.10                      | 5.36                  | 17.26                | 28.50   |
| 47                                     | 2                    | 5,302                     | --                     | 3.23        | 4.13        | 3.19                 | 6.24                      | 6.94                  | 38.55                | 37.72   |
| 48                                     | 2                    | 3,886                     | --                     | 23.34       | 1.11        | .08                  | .82                       | .75                   | 21.90                | 52.01   |
| 49                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 50                                     | 1                    | 1,158                     | --                     | 7.77        | 1.81        | --                   | --                        | 6.74                  | 29.88                | 53.80   |
| 51                                     | 1                    | 3,376                     | --                     | 31.69       | 4.00        | --                   | .09                       | --                    | 20.38                | 43.84   |
| 52                                     | 1                    | 1,113                     | --                     | 10.24       | .45         | 2.52                 | 3.86                      | 12.13                 | 19.14                | 51.66   |
| 53                                     | 1                    | 1,857                     | --                     | 6.14        | 2.75        | 2.53                 | .92                       | 2.21                  | 16.69                | 68.77   |
| 54                                     | 2                    | 5,028                     | --                     | 10.86       | 7.46        | .36                  | --                        | --                    | 30.09                | 51.23   |
| 55                                     | 4                    | 7,903                     | --                     | 9.74        | 2.13        | 1.37                 | 8.50                      | 15.56                 | 21.98                | 40.72   |
| 56                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 57                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 58                                     | 1                    | 2,003                     | --                     | 22.02       | 7.24        | .80                  | 5.59                      | 7.19                  | 27.86                | 29.31   |
| 59                                     | 1                    | 2,805                     | --                     | 1.89        | .18         | --                   | --                        | --                    | 22.25                | 75.69   |
| 60                                     | 1                    | 4,132                     | --                     | 2.59        | .27         | --                   | 3.90                      | 18.83                 | 57.50                | 16.92   |
| 61                                     | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 62                                     | 1                    | 2,671                     | --                     | 13.44       | 3.44        | 4.68                 | 10.63                     | .19                   | 17.52                | 50.09   |
| Total or<br>average                    | 62                   | 96,191                    | .04                    | 12.38       | 2.25        | 3.08                 | 5.33                      | 8.61                  | 27.64                | 40.67   |

TABLE 15.--Lumber grade yields expressed as a percent of lumber tally, when by cutting diameter, No. 2 Sawmill saw-length Saw Douglas-fir logs

| Log<br>length<br>(meter<br>inches) | Number<br>of<br>logs | Lumber<br>tally<br>volume | Lumber grade           |             |             |                      |                           |                       |                      |         |
|------------------------------------|----------------------|---------------------------|------------------------|-------------|-------------|----------------------|---------------------------|-----------------------|----------------------|---------|
|                                    |                      |                           | B and Better<br>Select | C<br>Select | D<br>Select | Select<br>Structural | No. 1 and<br>Construction | No. 2 and<br>Standard | No. 3 and<br>Utility | Economy |
| Board feet                         |                      |                           |                        |             |             |                      |                           |                       |                      |         |
| 10                                 | 2                    | 423                       | --                     | 0.71        | --          | --                   | --                        | 18.68                 | 34.28                | 46.34   |
| 11                                 | 3                    | 342                       | --                     | --          | --          | 6.14                 | 36.84                     | 30.70                 | 20.18                | 6.14    |
| 12                                 | 2                    | 395                       | --                     | --          | --          | --                   | 22.78                     | 22.78                 | 38.23                | 16.20   |
| 13                                 | 1                    | 84                        | --                     | --          | --          | --                   | 7.14                      | --                    | 20.24                | 72.62   |
| 14                                 | 2                    | 278                       | --                     | --          | --          | 3.60                 | 2.88                      | 11.51                 | 82.01                | --      |
| 15                                 | 4                    | 973                       | --                     | --          | --          | --                   | .82                       | 17.99                 | 67.32                | 13.87   |
| 16                                 | 1                    | 320                       | --                     | 7.19        | --          | 13.44                | 7.19                      | 68.75                 | --                   | 3.44    |
| 17                                 | 4                    | 1,301                     | --                     | --          | 1.00        | 3.31                 | 17.60                     | 26.06                 | 14.68                | 37.36   |
| 18                                 | 4                    | 628                       | --                     | --          | .80         | --                   | 22.93                     | 8.12                  | 32.96                | 35.19   |
| 19                                 | 7                    | 2,144                     | --                     | --          | --          | .14                  | 6.58                      | 26.40                 | 22.15                | 44.73   |
| 20                                 | 3                    | 722                       | --                     | --          | --          | --                   | --                        | 23.13                 | 27.42                | 49.45   |
| 21                                 | 3                    | 1,399                     | --                     | --          | --          | .21                  | 2.00                      | 32.59                 | 34.10                | 31.09   |
| 22                                 | 8                    | 3,714                     | --                     | .13         | --          | 1.45                 | 7.11                      | 18.66                 | 41.44                | 31.21   |
| 23                                 | 3                    | 1,688                     | --                     | .24         | --          | --                   | --                        | 12.03                 | 38.74                | 48.99   |
| 24                                 | 8                    | 5,294                     | --                     | .15         | --          | .91                  | 3.25                      | 20.57                 | 34.04                | 41.08   |
| 25                                 | 4                    | 1,773                     | --                     | --          | --          | 3.16                 | 10.04                     | 13.87                 | 39.93                | 32.99   |
| 26                                 | 6                    | 4,237                     | --                     | .17         | .12         | --                   | 7.67                      | 18.29                 | 35.69                | 38.07   |
| 27                                 | 3                    | 1,782                     | --                     | 3.48        | --          | 5.16                 | 5.44                      | 26.21                 | 31.87                | 27.83   |
| 28                                 | 5                    | 4,039                     | --                     | 3.00        | --          | 1.78                 | 8.05                      | 8.52                  | 40.63                | 38.03   |
| 29                                 | 4                    | 4,116                     | --                     | --          | --          | --                   | 3.11                      | 17.30                 | 48.59                | 31.00   |
| 30                                 | 4                    | 3,653                     | --                     | 1.51        | --          | 3.15                 | 4.79                      | 16.45                 | 53.30                | 20.80   |
| 31                                 | 8                    | 8,492                     | --                     | 1.78        | .16         | .51                  | 1.97                      | 19.27                 | 43.99                | 32.32   |
| 32                                 | 8                    | 9,320                     | --                     | 1.74        | .43         | .55                  | 3.76                      | 27.14                 | 36.76                | 29.64   |
| 33                                 | 2                    | 2,810                     | --                     | 1.60        | --          | .25                  | 1.57                      | 12.88                 | 61.67                | 22.03   |
| 34                                 | 4                    | 4,237                     | --                     | 3.45        | --          | 2.36                 | 9.25                      | 14.26                 | 39.51                | 31.18   |
| 35                                 | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 36                                 | 5                    | 6,684                     | 0.06                   | 3.05        | .91         | .48                  | 4.80                      | 7.97                  | 23.85                | 58.87   |
| 37                                 | 9                    | 14,498                    | --                     | 1.55        | .13         | .15                  | 2.91                      | 24.08                 | 54.51                | 16.67   |
| 38                                 | 3                    | 5,118                     | --                     | .39         | .43         | --                   | 9.55                      | 24.97                 | 34.29                | 30.36   |
| 39                                 | 3                    | 4,802                     | --                     | 4.08        | --          | .75                  | 1.79                      | 14.04                 | 30.65                | 48.69   |
| 40                                 | 2                    | 2,547                     | --                     | 6.20        | .31         | .24                  | 8.36                      | 8.32                  | 14.29                | 62.27   |
| 41                                 | 5                    | 9,008                     | --                     | 2.43        | 1.10        | .40                  | .81                       | 13.65                 | 44.75                | 36.86   |
| 42                                 | 3                    | 6,217                     | --                     | 7.11        | 1.40        | 2.22                 | 6.58                      | 11.95                 | 45.49                | 25.25   |
| 43                                 | 2                    | 2,573                     | --                     | .47         | .27         | 1.36                 | 5.09                      | 8.39                  | 33.27                | 51.15   |
| 44                                 | 4                    | 6,007                     | --                     | 2.01        | .22         | .32                  | 9.74                      | 18.43                 | 33.91                | 35.38   |
| 45                                 | 2                    | 4,410                     | --                     | --          | .45         | 2.00                 | 3.31                      | 5.51                  | 40.93                | 47.80   |
| 46                                 | 7                    | 16,391                    | --                     | 4.29        | .84         | 1.64                 | 1.31                      | 5.95                  | 37.09                | 48.88   |
| 47                                 | 3                    | 5,807                     | --                     | 3.69        | .67         | 1.08                 | 1.79                      | 9.92                  | 45.70                | 37.14   |
| 48                                 | 1                    | 1,962                     | --                     | --          | --          | --                   | 2.60                      | 24.62                 | 30.33                | 42.46   |
| 49                                 | 1                    | 1,445                     | --                     | 3.39        | --          | --                   | --                        | 3.32                  | 45.26                | 48.03   |
| 50                                 | 1                    | 2,201                     | --                     | 1.23        | .23         | .41                  | .95                       | .14                   | 44.48                | 52.57   |
| 51                                 | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 52                                 | 2                    | 3,965                     | --                     | 1.51        | .50         | --                   | 1.51                      | 3.40                  | 24.21                | 68.85   |
| 53                                 | 2                    | 4,448                     | 1.69                   | 8.09        | .90         | --                   | .74                       | 1.80                  | 17.83                | 68.95   |
| 54                                 | 1                    | 1,381                     | --                     | --          | --          | --                   | --                        | --                    | 2.32                 | 97.68   |
| 55                                 | 1                    | 1,998                     | --                     | 9.11        | --          | .55                  | 5.01                      | 5.36                  | 36.94                | 43.04   |
| 56                                 | 1                    | 1,764                     | --                     | --          | --          | --                   | --                        | --                    | 11.17                | 88.83   |
| or<br>average                      | 161                  | 167,390                   | .05                    | 2.38        | .39         | .91                  | 4.11                      | 14.74                 | 38.28                | 39.14   |



TABLE 16.--Lumber grade yields expressed as a percent of lumber tally volume by scaling diameter, No. 2 Sawmill woods-length Coast Douglas-fir Logs

| Log scaling diameter (inches) | Number of logs | Lumber tally volume | Lumber grade        |          |          |                   |                        |                    |                   |         |
|-------------------------------|----------------|---------------------|---------------------|----------|----------|-------------------|------------------------|--------------------|-------------------|---------|
|                               |                |                     | B and Better Select | C Select | D Select | Select Structural | No. 1 and Construction | No. 2 and Standard | No. 3 and Utility | Economy |
| Board feet                    |                |                     |                     |          |          |                   |                        |                    |                   |         |
| 14                            | 1              | 178                 | 0                   | 0        | 0        | 0                 | 47.75                  | 37.64              | 11.80             | 2.81    |
| 15                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 16                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 17                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 18                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 19                            | 1              | 878                 | 0                   | 0        | 0        | 0                 | 7.52                   | 25.85              | 26.65             | 39.98   |
| 20                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 21                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 22                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 23                            | 1              | 1,322               | 0                   | .61      | .91      | 29.27             | 21.48                  | 25.34              | 18.61             | 3.78    |
| 24                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 25                            | 2              | 3,248               | 0                   | 11.24    | .09      | .89               | 12.65                  | 12.01              | 24.29             | 38.82   |
| 26                            | 1              | 700                 | 0                   | 1.57     | 0        | 1.57              | 3.86                   | 6.71               | 74.57             | 11.71   |
| 27                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 28                            | 1              | 1,833               | 0                   | 2.56     | 0        | 4.80              | 22.09                  | 50.46              | 18.11             | 1.96    |
| 29                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 30                            | 1              | 2,811               | 0                   | 0        | 0        | 0                 | 0                      | 0                  | .82               | 99.18   |
| 31                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 32                            | 2              | 2,343               | 0                   | 5.25     | 1.02     | 2.18              | 5.46                   | 15.32              | 43.96             | 26.80   |
| 33                            | 1              | 1,820               | 0                   | 3.57     | 0        | 1.76              | 17.03                  | 27.53              | 29.73             | 20.38   |
| 34                            | 2              | 6,021               | 0                   | 19.60    | 1.99     | 7.14              | 14.50                  | 17.57              | 19.50             | 19.70   |
| 35                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 36                            | 2              | 6,225               | .06                 | 8.10     | 1.51     | 0                 | 3.28                   | 9.65               | 30.09             | 47.31   |
| 37                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 38                            | 2              | 6,828               | 0                   | 13.62    | 0        | .34               | 1.07                   | 15.79              | 29.04             | 40.14   |
| 39                            | 1              | 4,616               | 0                   | 19.43    | 3.90     | 8.82              | 1.19                   | 8.08               | 14.30             | 44.28   |
| 40                            | 3              | 10,826              | 0                   | 7.19     | 1.82     | .82               | 2.07                   | 6.16               | 45.39             | 36.55   |
| 41                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 42                            | 2              | 4,188               | .33                 | 3.99     | 3.03     | 2.39              | 6.64                   | 7.69               | 17.88             | 58.05   |
| 43                            | 1              | 3,936               | 0                   | 2.08     | 0        | 1.63              | .76                    | 21.47              | 38.82             | 35.24   |
| 44                            | 2              | 7,530               | 0                   | .41      | 1.54     | 2.35              | 7.89                   | 6.56               | 40.78             | 40.46   |
| 45                            | 3              | 12,050              | 0                   | 25.19    | 3.10     | 2.31              | 3.27                   | 7.93               | 19.76             | 38.46   |
| 46                            | 2              | 8,022               | 0                   | 1.98     | 1.13     | .59               | .85                    | 8.36               | 23.97             | 63.11   |
| 47                            | 1              | 4,847               | 0                   | 2.95     | 1.57     | 5.78              | 5.57                   | 3.80               | 21.39             | 58.94   |
| 48                            | 1              | 3,519               | 0                   | .68      | .28      | 0                 | 0                      | 1.99               | 8.27              | 88.78   |
| 49                            | 1              | 4,748               | 0                   | 25.13    | 3.58     | 0                 | .06                    | 0                  | 19.59             | 51.64   |
| 50                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 51                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 52                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 53                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 54                            | 1              | 4,001               | 0                   | 15.57    | 3.62     | .67               | 5.30                   | 6.27               | 32.39             | 36.17   |
| 55                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 56                            | 0              | --                  | --                  | --       | --       | --                | --                     | --                 | --                | --      |
| 57                            | 1              | 6,803               | 0                   | 6.85     | 1.51     | 1.84              | 6.54                   | 11.51              | 41.81             | 29.94   |
| Total or average              | 36             | 109,293             | .02                 | 9.91     | 1.68     | 2.42              | 4.98                   | 10.25              | 27.81             | 42.93   |

TABLE 17.--Lumber grade yields expressed as a percent of lumber tally volume by logging diameter, No. 3 Sawmill woods-length Coast Douglas-fir logs

| Log<br>coring<br>diameter<br>(inches) | Number<br>of<br>logs | Lumber<br>tally<br>volume | Lumber grade           |             |             |                      |                           |                       |                      |         |
|---------------------------------------|----------------------|---------------------------|------------------------|-------------|-------------|----------------------|---------------------------|-----------------------|----------------------|---------|
|                                       |                      |                           | B and Better<br>Select | C<br>Select | D<br>Select | Select<br>Structural | No. 1 and<br>Construction | No. 2 and<br>Standard | No. 3 and<br>Utility | Economy |
| Board feet                            |                      |                           |                        |             |             |                      |                           |                       |                      |         |
| 10                                    | 2                    | 366                       | 0                      | 0.82        | 0           | 0                    | 7.38                      | 2.19                  | 65.30                | 36.69   |
| 11                                    | 5                    | 1,733                     | 0                      | 1.33        | 0           | 3.69                 | 12.93                     | 35.83                 | 22.33                | 52.84   |
| 12                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 13                                    | 4                    | 702                       | 0                      | 0           | 0           | 7.55                 | 15.67                     | 25.93                 | 41.60                | 57.83   |
| 14                                    | 3                    | 1,370                     | 0                      | .29         | 0           | 0                    | .58                       | 13.65                 | 52.92                | 39.26   |
| 15                                    | 3                    | 794                       | 0                      | 0           | 2.64        | 0                    | 10.71                     | 8.19                  | 57.30                | 41.18   |
| 16                                    | 2                    | 655                       | 0                      | 0           | 0           | 0                    | 14.66                     | 3.66                  | 3.05                 | 28.79   |
| 17                                    | 2                    | 1,782                     | 0                      | .28         | .73         | 0                    | .84                       | 7.24                  | 29.91                | 27.71   |
| 18                                    | 6                    | 2,494                     | 0                      | 0           | .20         | .20                  | 2.69                      | 8.62                  | 33.76                | 31.73   |
| 19                                    | 3                    | 1,976                     | 0                      | 0           | 0           | 1.37                 | 14.98                     | 51.97                 | 22.67                | 62.23   |
| 20                                    | 3                    | 1,734                     | 0                      | .40         | .29         | 0                    | 8.48                      | 16.44                 | 29.41                | 36.17   |
| 21                                    | 2                    | 2,841                     | 0                      | 0           | 0           | 0                    | 3.06                      | 17.28                 | 56.67                | 40.53   |
| 22                                    | 4                    | 4,787                     | 0                      | 2.17        | .23         | 2.95                 | 3.43                      | 23.96                 | 49.13                | 48.35   |
| 23                                    | 2                    | 3,040                     | 0                      | 0           | 0           | 0                    | 0                         | 11.94                 | 56.51                | 34.61   |
| 24                                    | 3                    | 4,488                     | 0                      | 1.16        | 0           | 4.95                 | 13.57                     | 26.76                 | 43.83                | 54.54   |
| 25                                    | 1                    | 1,762                     | 0                      | 0           | 0           | 0                    | .23                       | 5.56                  | 36.32                | 28.37   |
| 26                                    | 2                    | 3,247                     | 0                      | 1.97        | 0           | 0                    | .99                       | 36.40                 | 30.64                | 49.15   |
| 27                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 28                                    | 2                    | 3,369                     | 0                      | 2.91        | 0           | .50                  | 3.27                      | 21.04                 | 47.61                | 41.26   |
| 29                                    | 2                    | 2,928                     | 0                      | 1.88        | 0           | .58                  | 7.10                      | 14.52                 | 51.33                | 40.31   |
| 30                                    | 1                    | 1,992                     | 0                      | 2.31        | .55         | 0                    | 2.11                      | 9.74                  | 47.24                | 33.76   |
| 31                                    | 3                    | 7,210                     | 0                      | 1.11        | .40         | 2.68                 | 8.52                      | 26.53                 | 34.94                | 49.50   |
| 32                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 33                                    | 3                    | 9,073                     | 0                      | 1.83        | .23         | .41                  | 1.23                      | 9.89                  | 53.79                | 39.42   |
| 34                                    | 2                    | 4,809                     | 0                      | 5.05        | .31         | 2.81                 | 10.02                     | 8.73                  | 25.10                | 45.26   |
| 35                                    | 5                    | 15,093                    | 0                      | 1.29        | .23         | .21                  | 2.63                      | 8.92                  | 47.19                | 38.99   |
| 36                                    | 2                    | 6,654                     | 0                      | 5.50        | .63         | .36                  | 2.07                      | 27.97                 | 46.35                | 52.24   |
| 37                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 38                                    | 4                    | 14,294                    | 0                      | 2.80        | .42         | .62                  | 1.47                      | 9.41                  | 42.98                | 35.83   |
| 39                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 40                                    | 1                    | 2,832                     | 1.24                   | 13.42       | 5.90        | 1.27                 | .95                       | 5.83                  | 14.37                | 50.17   |
| 41                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 42                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 43                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 44                                    | 2                    | 7,886                     | 0                      | 2.32        | .16         | .60                  | 7.58                      | 12.57                 | 44.34                | 42.32   |
| 45                                    | 1                    | 3,568                     | 0                      | .81         | 0           | 0                    | 0                         | .20                   | 23.68                | 25.40   |
| 46                                    | 2                    | 4,557                     | 0                      | 4.15        | .70         | .22                  | .99                       | 5.66                  | 28.57                | 31.46   |
| 47                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 48                                    | 1                    | 5,329                     | 0                      | .99         | .09         | .17                  | .39                       | 1.20                  | 27.23                | 27.27   |
| 49                                    | 2                    | 8,481                     | 0                      | 4.59        | .39         | 0                    | 7.48                      | 15.91                 | 41.16                | 44.31   |
| 50                                    | 0                    | --                        | --                     | --          | --          | --                   | --                        | --                    | --                   | --      |
| 51                                    | 1                    | 4,818                     | 0                      | 1.58        | .35         | 0                    | 0                         | 0                     | 18.10                | 25.65   |
| all or<br>average                     | 81                   | 136,664                   | .03                    | 2.35        | .39         | .85                  | 4.10                      | 14.03                 | 39.95                | 40.47   |



Snellgrove, Thomas A., John W. Henley, and Marlin E. Plank  
1975. Lumber recovery from large, highly defective, low grade  
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A sample of 51 large diameter, highly defective, low grade  
Coast Douglas-fir trees were processed in a western Oregon  
sawmill. Lumber grade yields and recovery ratios are presented  
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117 woods-length logs and 223 sawn-length logs which, in turn,  
produced about 1/4 million board feet of rough-green lumber.  
Some key results of this study are compared with an earlier study.

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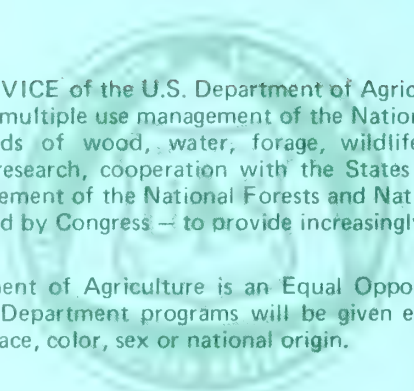
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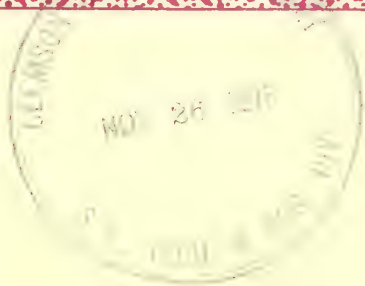
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1975

USDA Forest Service Research Paper PNW-198

# AUDIENCE ATTENTION AS A BASIS FOR EVALUATING INTERPRETIVE PRESENTATIONS



Ronald E. Dick  
Erik Myklestad  
J. Alan Wagar

PAACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

Department of Agriculture Forest Service

Portland, Oregon

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Ronald E. Dick is a doctoral candidate in the College of Forest Resources, University of Washington, Seattle. At the time this was written, Erik Myklestad and J. Alan Wagar were, respectively, research technician and project leader of the Environmental Interpretation Research Project, then maintained by the Pacific Northwest Forest and Range Experiment Station in cooperation with the University of Washington. Wagar has since become leader of the Forest Recreation Research Project maintained by the Northeastern Forest Experiment Station in cooperation with the State University of New York College of Environmental Science and Forestry, Syracuse, New York.

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# AUDIENCE ATTENTION AS A BASIS FOR EVALUATING INTERPRETIVE PRESENTATIONS

## Reference Abstract

Dick, Ronald E., Erik Myklestad, and J. Alan Wagar

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Unobtrusive procedures for observing audience attention were developed for evaluating effectiveness of interpretive presentations. Graphed results identified markedly different attention levels within a presentation and between presentations. Field personnel can apply the procedures to diagnose strengths and weaknesses in their presentations.

KEYWORDS: Recreation, information and education.

## RESEARCH SUMMARY

### Research Paper PNW-198

1975

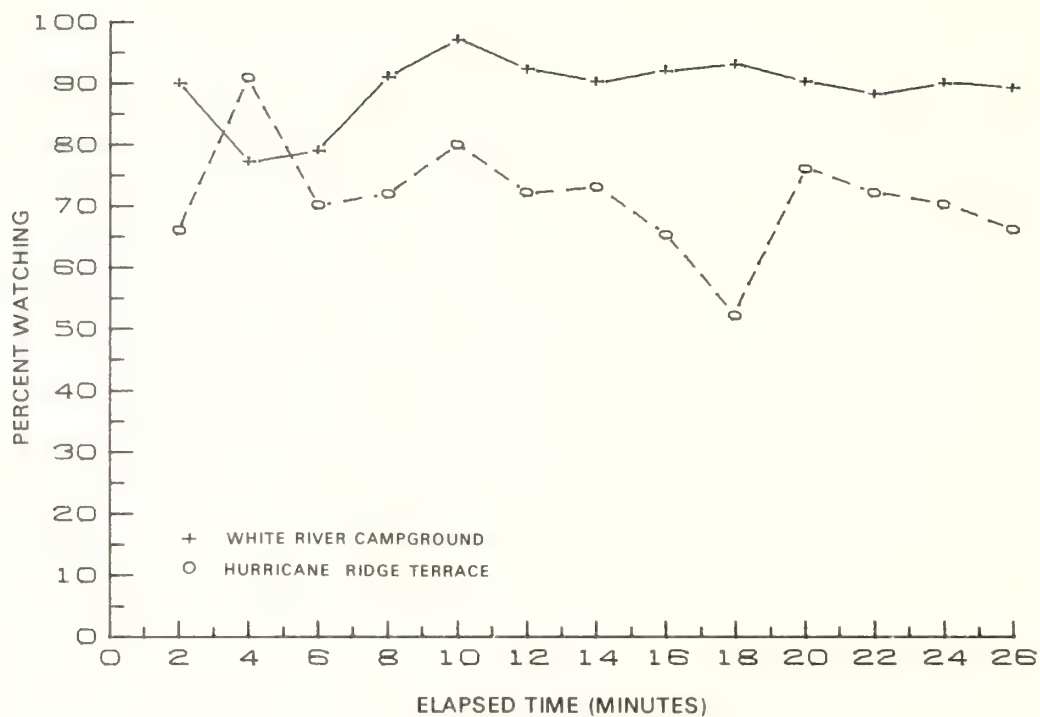
In a search for unobtrusive ways to evaluate and upgrade the effectiveness of such interpretive presentations as campfire programs and guided nature walks, a direct observation technique was developed. At each of two naturalist talks, a puppet show, and an audiovisual presentation, several audiences were studied. At frequent intervals two observers recorded the percentage of an audience watching the speaker or presentation. Observations were normally at 1-minute intervals for presentations of 20 minutes or less and at 2-minute intervals for longer presentations. Although people sometimes watch a presentation while thinking of other matters, percent watching appeared to correlate well with general audience responsiveness to a speaker or presentation.

Under ideal conditions (audience size under 20, good lighting, observers facing audience), percent watching was determined

by watching people's eyes. For less ideal conditions, orientation of people's heads toward a speaker or presentation was accepted as indicating attention. Although this introduced another source of error, such error did not obscure the great differences that occurred in percent watching.

After very little practice, the two observers consistently recorded comparable results. Graphed observations showed that differences in attention levels were readily detected both within a presentation and between presentations. Such differences permit field personnel to identify strengths and weaknesses in interpretive presentations. This is facilitated by tape recording the presentations for later comparison with graphs and by noting apparent causes of attention or inattention in the "remarks" column of the observation form.





*Comparison of audience attention at campfire program, White River Campground, Mount Rainier National Park and at naturalist talk on terrace, Hurricane Ridge Visitor Center, Olympic National Park.*

## Introduction

In the United States, agencies involved in outdoor recreation have interpreted natural and cultural history for their visitors for many years. However, the effectiveness of these presentations has seldom been evaluated. Attempts at evaluation have usually meant observation of the interpreter's technique by a supervisor. Although supervisors can provide important guidance, the only sure test of effectiveness is to examine what we are trying to affect--the audience.

Perhaps the surest way to determine communication effectiveness is to administer a battery of questions testing the extent to which an audience has understood and, in some cases, been persuaded or convinced. However, for recreational settings, frequent questioning places an unacceptable burden on visitors. For routine monitoring, some less burdensome procedure is needed.

Among the many factors influencing the effectiveness of communication, prior investigations have shown that a message's ability to attract and hold attention is fundamental to its effectiveness.<sup>1/</sup> Communication occurs only when the intended audience pays heed to incoming messages.

This paper focuses on audience attention. Specifically, it describes a direct observation method that permits field personnel to monitor audience attention to an ongoing interpretive presentation. By recording attention levels at intervals throughout such presentations, this unobtrusive feedback procedure facilitates evaluation and improvement.

---

<sup>1/</sup>Carl I. Hovland, Irving L. Janis, and Harold H. Kelley. *Communication and persuasion*. Yale University Press, New Haven. 315 p., 1953.

## The Presentations Studied

Three types of presentations observed during the summer of 1973 are discussed: a "canned" audiovisual program, puppet shows, and naturalist talks. The audiovisual program was at the Paradise Visitor Center in Mount Rainier National Park, Washington; it interpreted relationships among Park fauna, using a rear screen slide projection console surrounded by cases of mounted animals. The slides and shifting illumination of the cases were synchronized with an audiotape. Three broad carpeted risers provided informal seating for the presentation, which lasted 10 minutes and was given many times a day. The two observers used the many audiences at this automated exhibit for training, comparing their results for each audience observed and discussing reasons for differences.

The puppet theater was a part of the exhibition "Energy and Its Relation to Man and the Environment" presented at the Pacific Science Center, Seattle, Washington. The puppeteers remained the same throughout the observations. However, improvisation was a major aspect of the presentations. The shows were given whenever enough visitors were available for an audience. Members of the audience could sit, stand, or recline on pillows in a triangular floor area. The shows were presented in an area where they competed with other exhibits.

Naturalist talks were observed at the Hurricane Ridge Visitor Center, Olympic National Park, Washington, and the White River Campground, Mount Rainier National Park. The talks at Hurricane Ridge covered the flora, fauna, and geology of Olympic National Park and were given by Park interpreters on the terrace overlooking the Olympic Mountains. The talks at White River Campground centered around Indian legends and were given by Park interpreters

at the campground amphitheater. In both settings, members of the audience sat on wooden benches and had many opportunities to be distracted by such things as wildlife, weather, and scenery.

## Procedures

Because interpretive presentations are continuous, ongoing communications, questions to an audience would either interrupt this ongoing process or would investigate it as a past event. Therefore, five nonverbal indicators were selected for analyzing fluctuations in audience attention: percentage watching the presentation, fidgeting, talking, leaving during the presentation, and response to instructions given during the presentation.

Initial observations quickly showed that the percentage of the audience watching the presentation, hereafter called "percent watching," was the most workable measure of audience attention for the interpretive presentations studied. Although individuals sometimes watch a presentation while thinking of other things, percent watching appeared to correlate well with general audience responsiveness to a speaker or presentation.

Observing visitors' eyes was possible only with small audiences (under 20), good lighting conditions, and with the observers facing the audience. When conditions were less than ideal, the orientation of people's heads toward the presentation was used as an operational definition of audience attention. This introduced an additional source of error but did not obscure the great differences that occurred in percent watching.

By observation of either visitors' eyes or the direction of their heads, data were collected to determine (1) the consistency of results obtained by two observers, (2) how many people were actually paying

attention at different points in the presentation, and (3) factors having positive or negative effects on audience attention.

At preselected intervals, two observers recorded the number of people in the audience and the number actually watching the presentation. The usual frequency of scanning was once a minute for programs of 20 minutes or less and once every 2 minutes for longer presentations. Persons too well hidden to be observed were not considered to be part of the audience. The two observers began each scan at exactly the same time and used the same scanning patterns--e.g., front to back, left to right.

Differences in measurement inevitably occur when two observers examine the same segment of the audience at slightly different times. Fortunately, differences from this source were slight relative to the substantial differences found in percent watching. The two observers scanned for attention or nonattention--depending on which was the less predominant. If more people were paying attention than not, observers counted those not paying attention, and vice versa.

## Results and Discussion

Direct observation of an audience can provide reliable feedback on visitor attention to an interpretive presentation. Although the two observers in this study did not always record exactly the same "percent watching" scores, they consistently recorded the same patterns of fluctuation in audience attention (figs. 1, 2, and 3).

Methodical observation can identify differences in audience attention within a presentation (figs. 1, 2, and 3) and between presentations (fig. 4). In addition it permits evaluation of efforts to increase attention to interpretive presentations.

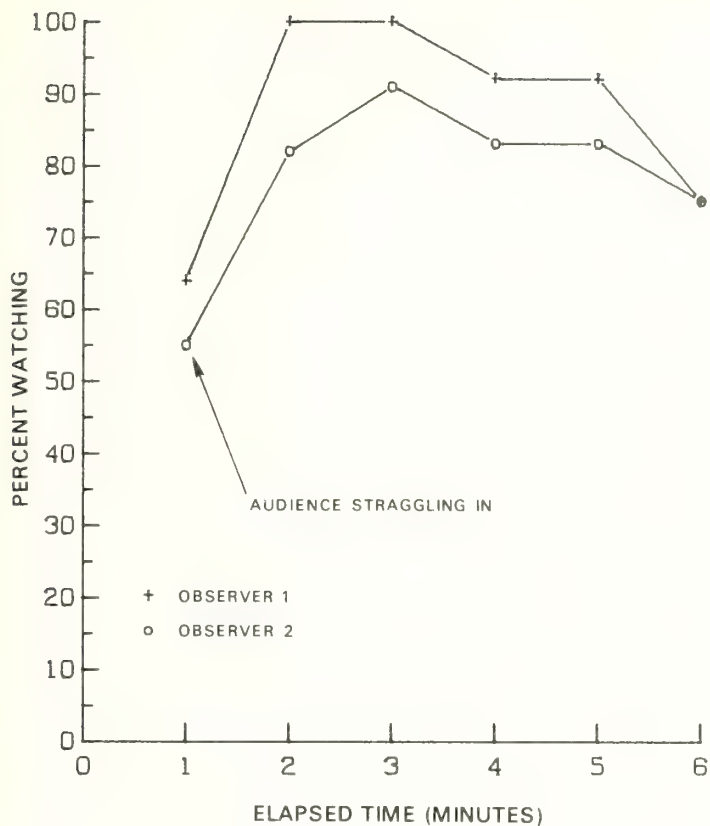


Figure 1.--Percent of audience watching presentation, as determined by observation of visitors' eyes--audiovisual presentation on Park fauna, Paradise Visitor Center, Mount Rainier National Park, 3:45 p.m., August 13, 1973.

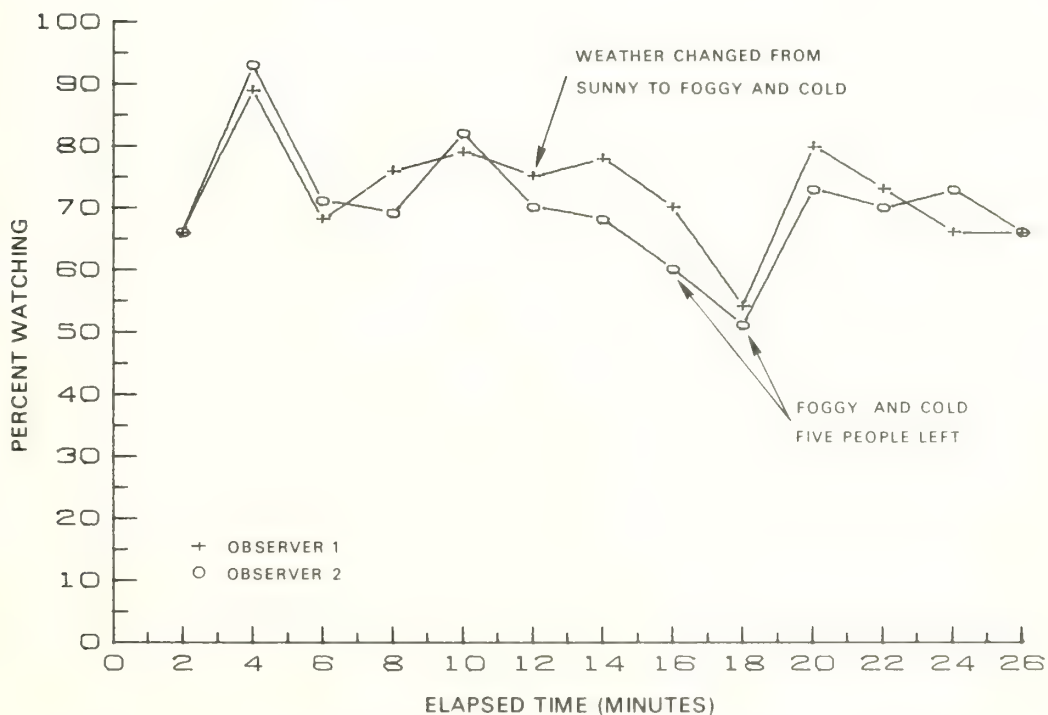


Figure 2.--Percent of audience watching presentation, as determined by observation of visitors' eyes--lecture on terrace at Hurricane Ridge Visitor Center, Olympic National Park, 1:30 p.m., August 22, 1973.

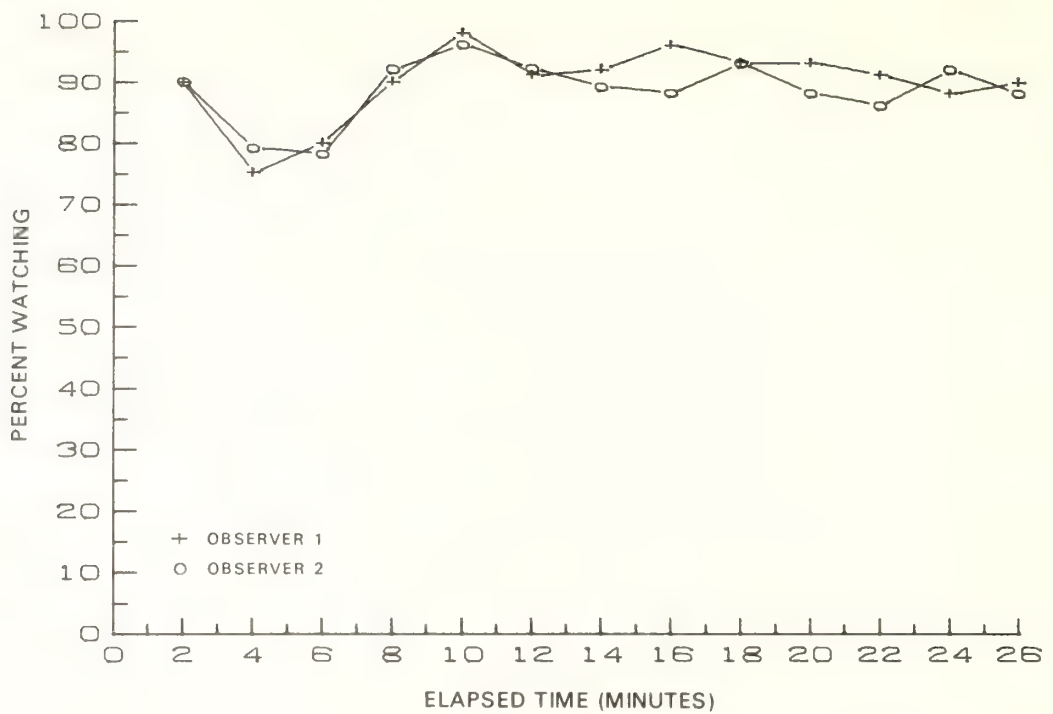


Figure 3.--Percent of audience watching presentation, as determined from direction of visitors' heads--campfire talk at White River Campground amphitheater, Mount Rainier National Park, 8:00 p.m., August 13, 1973.

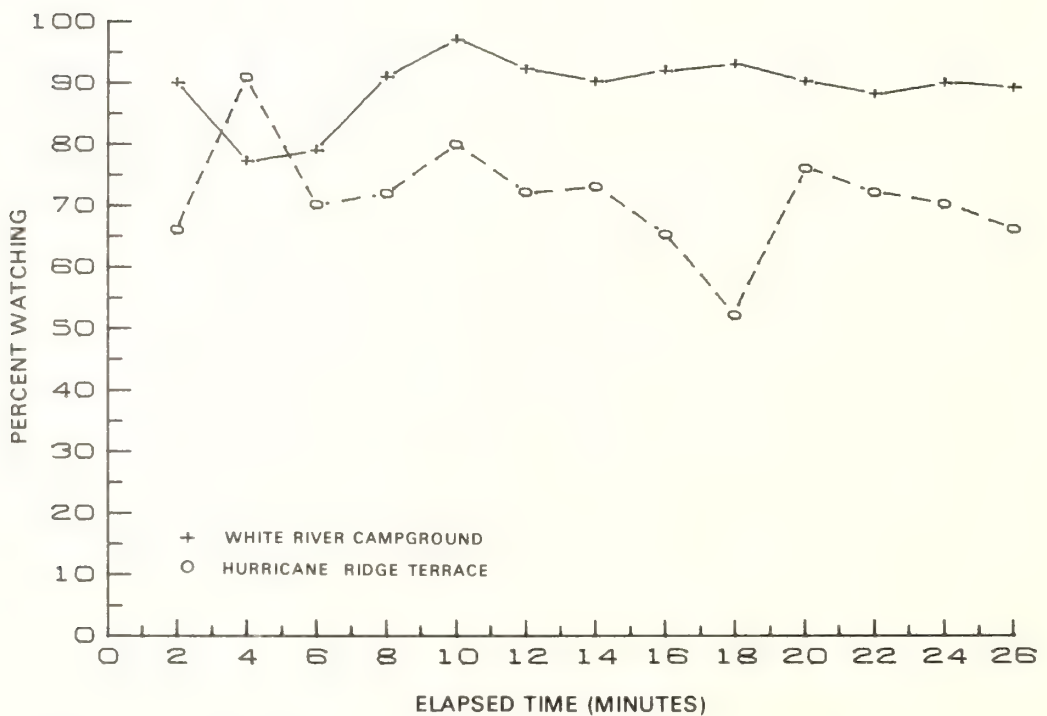


Figure 4.--Comparison of percent of audience watching presentations at Hurricane Ridge Visitor Center (fig. 2) and White River Campground (fig. 3). (Data from the two observers have been averaged.)



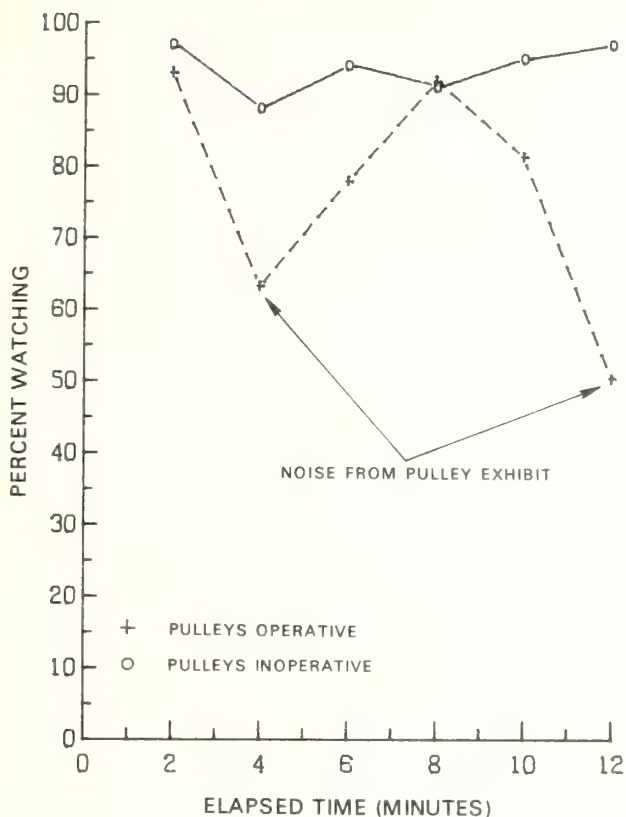


Figure 5.--Percent of audience watching puppet show before and after noise from a nearby pulley exhibit was eliminated, Pacific Science Center, Seattle, Washington, 1:30 p.m. (pulleys operative) and 3:30 p.m. (pulleys inoperative), August 8, 1973. Percent watching determined by observation of visitors' eyes.

For example, figure 5 shows attention levels for a puppet show before and after distracting noise from a nearby exhibit was eliminated. An exhibit demonstrating pulleys created much clatter, especially when chords were released, permitting weights to drop. Observers' remarks for one puppet show identified low attention levels at the 4- and 12-minute points as resulting from distracting noise at the pulley exhibit. During the second show, the pulley exhibit was inoperative and attention levels remained consistently high.

## Application

The ideal position for observers is to one side of the audience, near the front, elevated, and at least partly screened from view by the audience. Because conditions seldom are this ideal, observers must select or develop the best position available.

For complete records, observers should use a printed form (fig. 6). Records are easiest to interpret when graphed. In conjunction with remarks on the observation

# RECORD OF AUDIENCE ATTENTION TO INTERPRETIVE PRESENTATION

|                                                                                                      |                                                                                                                    |                                                      |
|------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| Title and description of presentation:<br><i>Naturalist talk White River<br/>(Camp ground, HJRM)</i> | Attention defined as<br>Eye contact <input type="checkbox"/><br>Head direction <input checked="" type="checkbox"/> | Observer:<br><i>R.L. Dick</i><br>Date <i>8/13/73</i> |
|------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|

| TIME              | ATTENTION                                                  | AUDIENCE SIZE <sup>2</sup> |          |            | Percent giving attention | REMARKS                     |
|-------------------|------------------------------------------------------------|----------------------------|----------|------------|--------------------------|-----------------------------|
| Started           | Number showing attent. <sup>1</sup> inattent. <sup>1</sup> | At beginning               | arrivals | departures |                          |                             |
| E: 6:07pm<br>Plus |                                                            | 41                         |          | Subtotal   |                          |                             |
| 01 02             | 43 4                                                       |                            |          | 47         | 91                       | Beginning Campfire          |
| 02 04             | 36 12                                                      | 1                          |          | 48         | 75                       | Campfire smoke on audience  |
| 03 06             | 46 10                                                      | 2                          |          | 50         | 80                       | " " "                       |
| 04 08             | 45 5                                                       |                            |          | 50         | 90                       | Beginning of Indian legends |
| 05 10             | 51 1                                                       | 2                          |          | 52         | 98                       |                             |
| 06 12             | 58 6                                                       | 12                         |          | 64         | 91                       |                             |
| 07 14             | 57 5                                                       |                            | 2        | 62         | 92                       |                             |
| 08 16             | 64 3                                                       | 5                          |          | 67         | 96                       |                             |
| 09 18             | 64 5                                                       | 2                          |          | 69         | 93                       |                             |
| 10 20             | 64 5                                                       |                            |          | 69         | 93                       |                             |
| 11 22             | 63 6                                                       |                            |          | 69         | 91                       |                             |
| 12 24             | 63 9                                                       | 3                          |          | 72         | 88                       |                             |
| 13 26             | 65 7                                                       |                            |          | 72         | 90                       |                             |
| 14 28             |                                                            |                            |          |            |                          |                             |
| 15 30             |                                                            |                            |          |            |                          |                             |
| 16 32             |                                                            |                            |          |            |                          |                             |
| 17 34             |                                                            |                            |          |            |                          |                             |
| 18 36             |                                                            |                            |          |            |                          |                             |
| 19 38             |                                                            |                            |          |            |                          |                             |
| 20 40             |                                                            |                            |          |            |                          |                             |
| 21 42             |                                                            |                            |          |            |                          |                             |
| 22 44             |                                                            |                            |          |            |                          |                             |
| 23 46             |                                                            |                            |          |            |                          |                             |
| 24 48             |                                                            |                            |          |            |                          |                             |
| 25 50             |                                                            |                            |          |            |                          |                             |
| 26 52             |                                                            |                            |          |            |                          |                             |
| 27 54             |                                                            |                            |          |            |                          |                             |
| 28 56             |                                                            |                            |          |            |                          |                             |
| 29 58             |                                                            |                            |          |            |                          |                             |
| 30 60             |                                                            |                            |          |            |                          |                             |

Ended

*8:32 pm*

Additional remarks (Identify by time interval and use back of form if necessary):

Audience size

at end: *72*

<sup>1</sup> Record attention or inattention, whichever is smaller.

<sup>2</sup> Subtotals and percentages should be computed in office with calculator.

Figure 6.--Form for recording audience attention to interpretive presentations.

form, a tape recording of a presentation may permit fluctuation in attention to be associated with factors either within or outside the presentation. Videotaping the presentation might be even more helpful.

One trained observer can usually observe attention in audiences up to about 40 people. Two or more observers can divide a larger audience into two or more observation zones. Or a single observer can let one part of the audience represent the total. In doing so, he should be careful to avoid a preponderance of similar people--such as youth groups, those who sit in front rows, tour groups, etc.

Observers should be trained in small groups so they can compare results and develop reliability. During training, all observers should synchronize their scanning intervals and patterns so that they observe the same people at approximately the same times. Also during training, each observer should examine the same people; that is, people hidden from any observer should be ignored by all.

With practice, observers will be able to score audience attention by looking at entire sections of the audience rather than sequentially observing each individual.









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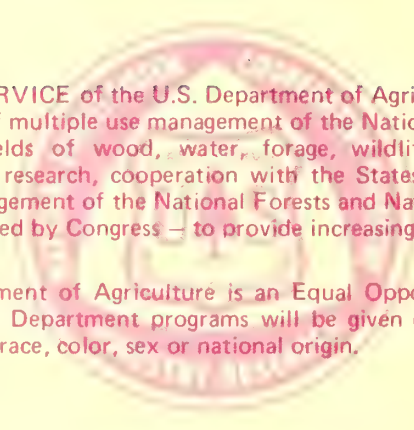
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# Particle Sizes in Slash Fire Smoke



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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION  
U.S. DEPARTMENT OF AGRICULTURE  
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# PARTICLE SIZES IN SLASH FIRE SMOKE

## Reference Abstract

Sandberg, David V., and Robert E. Martin

1975. Particle sizes in slash fire smoke. USDA For. Serv. Res. Pap. PNW-199, 7 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Particulate emissions are the most objectionable atmospheric contaminant from forest burning. Little is known of the particulate sizes, and this research was done under laboratory conditions to obtain particle size information. Comments are made concerning techniques for future work in this field.

KEYWORDS: Air pollution (slash disposal), prescribed burning (-particulates).

## RESEARCH SUMMARY

### Research Paper PNW-199

1975

Forest burning contributes a substantial amount of emissions to the atmosphere each year. The particulate fraction of the emissions is most objectionable from the standpoint of visibility, esthetics, and atmospheric degradation. Little is known of the sizes and configuration of the particulates, and this study was conducted to gain a better understanding of particulate characteristics emitted in slash burning. Impactor studies revealed 82 percent of particulate mass was less than 1- $\mu$ m (micrometer) aerodynamic diameter and 69 percent was less than 0.3  $\mu$ m. Scanning electron microscopy revealed four types of particles: (1) single spherical submicrometer particles 0.05- to 0.6- $\mu$ m diameter with most of them close to 0.1  $\mu$ m; (2) an agglomeration of the first particle type into chains up to 4  $\mu$ m long or spheres up to 80- $\mu$ m diameter and containing at least 200 small particles; (3) nearly spherical particles from <1- $\mu$ m to 12- $\mu$ m diameter; (4) angular particles from <0.05 to about 20  $\mu$ m in largest dimension.

Prescribed forest burning is a source of emissions into the atmosphere in the Pacific Northwest, as it is in some other forested regions in

the United States. Burning of forest fuels has been estimated to produce 23.7 percent of the 6.1 million metric tons of particulates emitted to the atmosphere each year and 6.9 percent of the 2.0 million metric tons of hydrocarbons (National Air Pollution Control Administration 1970) (a metric ton equals 1.12 short tons). Increased public awareness of air pollution has focused unfavorable attention on the burning of logging slash. The burning of 6.3 million metric tons of forest residue in Washington and Oregon annually releases 45,000 metric tons of hydrocarbons and 76,000 metric tons of particulate matter into the atmosphere.<sup>1/</sup> Wildfires contribute even more, but estimates are difficult to make.

The purpose of this paper is to present data on the relative mass of submicrometer (<1- $\mu$ m or <10<sup>-6</sup>-m), large (1- to 5- $\mu$ m), and giant (>5- $\mu$ m) particles

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<sup>1/</sup> G. R. Fahnestock. A problem analysis--impacts of forest residues and their disposal on forest land management and environment in the Pacific Northwest. Unpublished report, 28 p., 1968. On file, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

released from the laboratory burning of slash-type fuels. In addition, the size range and shape of particles will be reported. In part, this was a pilot study, and we'll comment on appropriate techniques for future slash burning air pollution studies.

## PREVIOUS WORK

First, we might delineate some general air pollution problems that are not created by forest burning. Sulfur dioxide is not created by forest burning, and temperatures are too low for the emission of significant amounts of the oxides of nitrogen. The hydrocarbons formed are generally not photochemically reactive, nor have they been shown to be a health hazard. The worst that can be said of them is that they may condense to form visible aerosols (Hall 1972).

Particulate emissions, on the other hand, can degrade air quality by reducing visibility. Northwest air is polluted more by particulates than other pollutants when compared by Federal standards,<sup>2/</sup> so reduction of particulate emissions in smoke sensitive areas is the current priority of most local air pollution authorities. Also, there is a generally negative public reaction to any smoke or other material that is added to the atmosphere, whether or not it constitutes air pollution (Cramer 1969).

Little is known directly about the quantity or quality of pollutants released from burning of forest residues; most of what is known is extrapolated from experiments of burning other agricultural fuels. Many components of the hydrocarbon fraction have been described (Fritschen et al. 1970), and other relevant experiments are underway. Hall (1972) summarizes the knowledge. Of the important particulate fraction, however, the very least is known.

Of all the properties of particles in the air, none dominates their behavior more (nor is more difficult to study experimentally) than size. The

laws governing many important properties of aerosols, including light scattering, coagulation, predominance of diffusion or settling, rate of cooling, and microscopic visibility, change fundamentally as the particle radius approaches the mean free path of the gas molecules,  $0.07 \mu\text{m}$  in air at standard conditions; or with the average wavelength of visible light,  $0.55 \mu\text{m}$ . The effect of an aerosol on visibility is determined more by particle size than by concentration. In general, a particle of  $1 \mu\text{m}$  or more in diameter scatters light in proportion to the square of its radius; a submicrometer particle scatters light in proportion to the sixth power of its radius (Fuchs 1964).

The mechanisms for removal of particles from the atmosphere also depend on particle size. In general, submicrometer particles have settling velocities less than  $3.5 \times 10^{-3} \text{ cm}\cdot\text{s}^{-1}$ , are dominated by Brownian motion, diffuse in air, and remain suspended for days or more, while larger particles will settle out of still air. Particles with a radius comparable to or smaller than the mean free path of air molecules will not settle out (Green and Lane 1964).

Numerous authors, as summarized by Brown et al. (1950), have recognized the relationship between particle size and lung penetration in man. They conclude that nasal efficiency for screening out airborne particles entering the respiratory tract is 100 percent for particles above  $5 \mu\text{m}$  and decreases with size to zero for  $1\text{-}\mu\text{m}$  particles. They also found that alveolar retention is complete for particles larger than  $1 \text{ micrometer}$  that are not filtered out by the upper respiratory tract. Optimum particle size with the highest probability of alveolar deposition is about  $1\text{-}\mu\text{m}$  diameter. Smaller particles down to  $0.25 \mu\text{m}$  have about the same probability of being retained in the alveoli as those from  $1 \text{ to } 5 \mu\text{m}$ . Wells (1955) pointed out that it is not the projected diameter but the aerodynamic dimension that determines lung penetrability.

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<sup>2/</sup> Washington State Department of Ecology. Summary of the implementation plan for attainment of the national ambient air quality standards. Mimeographed, 30 p., 1972.



Aerodynamic dimension is the size of a spherical particle that would have the same falling velocity as the particle described. Projected diameter is the diameter of a circle having the same area as a cross section of the particle.

There is some controversy in the literature concerning the particle sizes in wood fire smoke. Feldstein and his associates (1963) estimated that 50 percent of the particulate mass from the burning of land clearing debris is in the 50- to 100- $\mu\text{m}$  size range. The data were derived from the examination of microscope slides placed around fires to collect fallout. However, Meland and Boubel (1966) measured smoke from field burning and found that particles were uniformly distributed in the submicrometer range. Haessler (1965) said that smoke particles, as initially formed, are usually about 0.1  $\mu\text{m}$ . MacArthur (1966) collected particles from bush-fire smoke in a thermal precipitator. They ranged in size from 0.1 to 1.0  $\mu\text{m}$ , with a marked preponderance at about 0.1- $\mu\text{m}$  diameter. Vines and others (1971) conducted extensive experiments. Using a variety of sizing techniques and aircraft traverses of smoke plumes, they found most of the particles collected appeared to be close to 0.1- $\mu\text{m}$  diameter, and that smoke contained few particles larger than 5  $\mu\text{m}$ . Some agglomerates of smaller particles were found as large as 50  $\mu\text{m}$ . Two types of small particles were found. Spherical, smooth particles thought to be tar were 0.2  $\mu\text{m}$  or more in diameter. Rough, crystalline ash and carbon particles between 0.05 and 0.03  $\mu\text{m}$  were found to be less numerous than the tar particles. Butcher and Charlson (1972) report that condensation of particles in flames produce submicrometer particles that may coalesce or agglomerate to clumps or chains before being emitted from the source.

Particulates may be the most important pollutant emitted from forest burning, but the least is known about them. Aerodynamic particle size is a

most important characteristic of particles, but there is disagreement on the proportion of large particles in smoke. Particle size determines the residence time of the particles in the air and their penetrability into human lungs. Large particles scatter light inefficiently, fall out rapidly, and are less important air pollutants than submicrometer particles.

## METHODS

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) slash was collected from a second-growth stand in western Washington 1 year after harvesting. From branches and twigs, a continuum of sizes less than 3-in (7.6-cm) diameter, 17 fuel beds were constructed in the laboratory. The surface-to-volume ratio of each fuel bed was 86  $\text{ft}^2/\text{ft}^3$  (282  $\text{m}^2/\text{m}^3$ ). Porosity, the ratio of fuel bed volume to fuel particle volume, ranged from 9 to 18 at ignition. Fuel moistures ranged from 11 to 23 percent of oven-dry fuel weight. The fuel beds weighed 13 lb (5.9 kg), corresponding to a slash loading of about 38 tons/acre (84 metric tons/ha).

The circumference of the fuel beds was ignited with a propane torch. Fuel weight loss was continuously recorded and converted to energy release rate in  $\text{Btu ft}^{-2}\cdot\text{min}^{-1}$  ( $\text{k cal}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$  and  $\text{J}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$ ). Smoke from the fires was contained in a hood vented by a 16-in (40.6-cm) diameter constant-volume-flow induced-draft flue. A sample was removed 15 ft (4.6 m) from the fuel bed via a 25-in-long (63.5-cm) sample line with a sharp inlet nozzle of 3/8-in (0.95-cm) diameter. The nozzle size provided isokinetic sampling within 10 percent, using a constant sample volume flow of 1  $\text{ft}^3\cdot\text{min}^{-1}$  (0.0283  $\text{m}^3\cdot\text{min}^{-1}$ ) at standard conditions.

The samples were drawn through an eight-stage Andersen impactor (Andersen 1966).<sup>3/</sup> According to the manufacturer,

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<sup>3/</sup> Mention of products by name does not constitute an endorsement by the U.S. Department of Agriculture.

the first two stages remove nearly all material over 5- $\mu\text{m}$  aerodynamic diameter, three stages remove large material, and two stages remove submicrometer particles to about 0.3  $\mu\text{m}$ . A 47-mm inline Gelman Type A glass-fiber filter as the last stage removes nearly all remaining solids or condensed liquids. Temperatures at the sample line inlet never exceeded 200° F (93° C). That temperature in the impactor produces only a 10-percent error in the indicated diameter of particles on each stage. The seven stainless steel impactor stages and the filter mat were weighed before and after sampling. The collection plates were cleaned only after five fires were sampled to allow adequate accumulation for accurate weight measurement.

Smoke from four of the fuel beds was sampled during the smoldering (postflaming) period only. The average intensity of the four fires was 126  $\text{Btu ft}^{-2}\cdot\text{min}^{-1}$  (342  $\text{k cal}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$  or  $1.43 \times 10^4 \text{ J}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$ ). Five fires, with intensities ranging from 353 to 1,417  $\text{Btu ft}^{-2}\cdot\text{min}^{-1}$  (958 to 3845  $\text{k cal}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$  or  $4.01 \times 10^4$  to  $16.1 \times 10^4 \text{ J}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$ ), were sampled during the entire flaming period. Eight fires were sampled only while the intensity was greater than one-half the peak for that fire. Intensities for that series ranged from 1,000 to 1,857  $\text{Btu ft}^{-2}\cdot\text{min}^{-1}$  (2712 to 5040  $\text{k cal}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$  or  $11.4 \times 10^4$  to  $21.1 \times 10^4 \text{ J}\cdot\text{m}^{-2}\cdot\text{min}^{-1}$ ).

Five additional fuel beds were burned to obtain samples of 0.4- $\mu\text{m}$  pore diameter nucleopore filter media for electron photomicrographs. Thirty-four samples, representing all phases of fire activity, were collected. One filter was placed on each stage of the Andersen sampler. Oblique photographs, with a 30-degree tilt angle, were taken on a scanning electron microscope. The photographs were used to determine the shape and size range of the particles.

## RESULTS

The electron microscope revealed four distinct types of particles. By far the most prevalent was the singular spherical submicrometer particle reported by other investigators (fig. 1). The

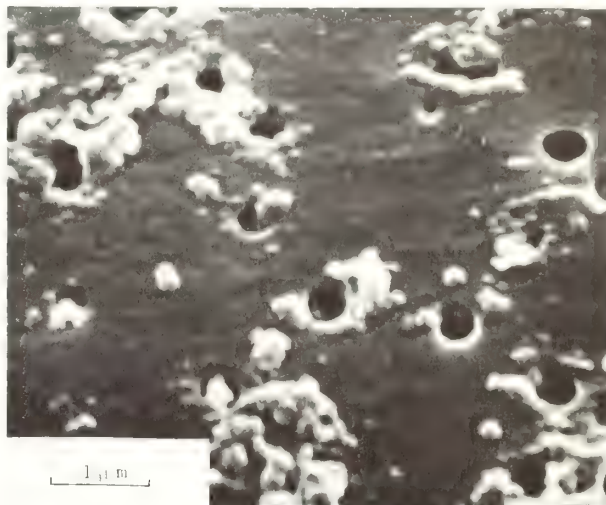


Figure 1.--Spherical submicrometer smoke particles from burning Douglas-fir slash (Scanning Electron Micrograph-SEM).

observed range of projected diameters was from less than 0.05 to 0.6  $\mu\text{m}$ . The limit of resolution in the photographs was slightly less than 0.05  $\mu\text{m}$ . Most of these spherical particles were very close to 0.1  $\mu\text{m}$ . These particles adhered to filter media, and solvents were required to remove them from metal surfaces.

The second type of particle observed was an agglomeration of the spherical particle above. Branched chains of particles up to 4  $\mu\text{m}$  long and containing at least 200 submicrometer spheres were seen, but not commonly (fig. 2). Roughly spherical agglomerates of a few to an estimated  $10^8$  small particles were commonly observed (fig. 3). The largest cluster seen had a projected diameter of about 80  $\mu\text{m}$  (not shown). The agglomerates accounted for the vast majority of all particles present with aerodynamic



diameters over 1  $\mu\text{m}$ . Agglomeration was apparently enhanced by the walls of the sampling line. When a 6-ft-long (1.83-m), 1/4-in-diameter (0.64-cm) sampling line was used, nearly all submicrometer particles agglomerated to large clusters. Agglomeration was still very common when a short (4-in or 10.16-cm), large-diameter (5/8-in or 1.59-cm) sample line was used, however.

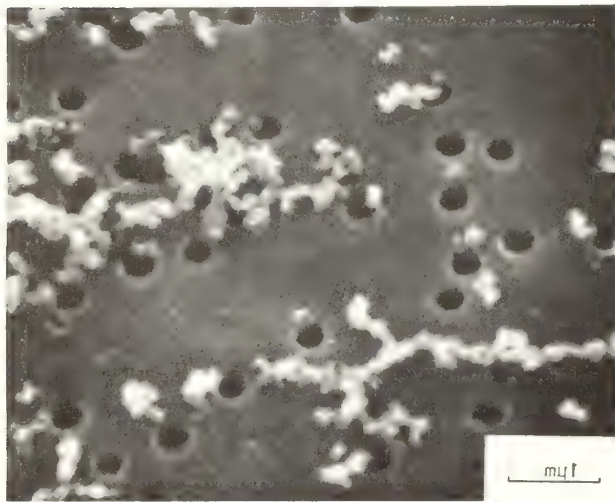


Figure 2.--Agglomerated chain of smoke particles from burning Douglas-fir slash (SEM).

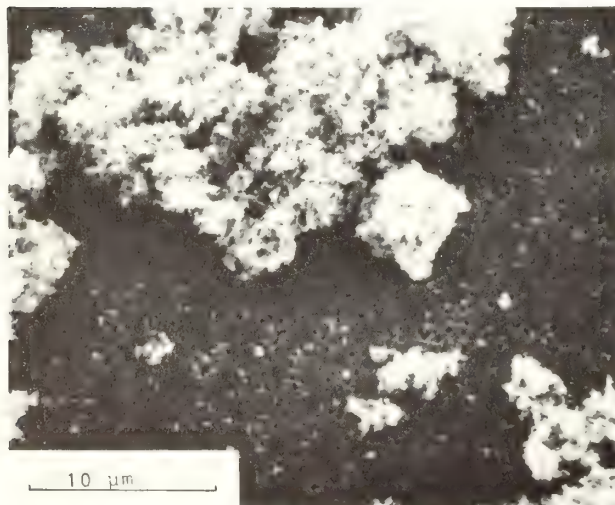


Figure 3.--Large clusters of spherical submicrometer smoke particles from burning Douglas-fir slash (SEM).

Solid, nearly spherical particles were also seen, ranging from less than 1  $\mu\text{m}$  to 12  $\mu\text{m}$  (fig. 4). The surface of

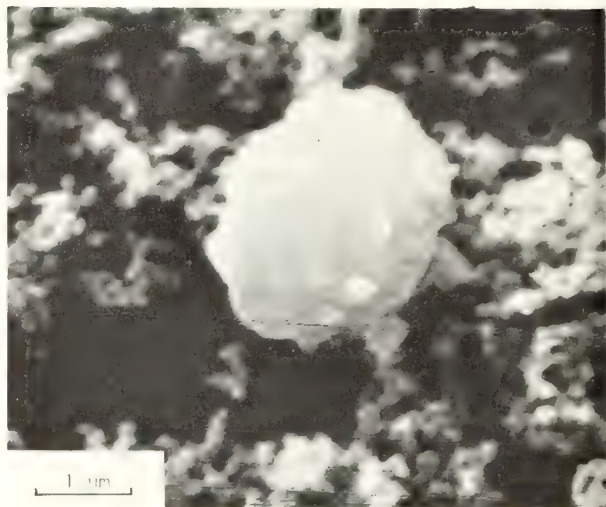


Figure 4.--Large, smooth, solid smoke particle from burning Douglas-fir slash (SEM).

the particles was textured with round protrusions of less than 1- $\mu\text{m}$  diameter, suggesting that they are also agglomerates of the submicrometer spheres above. These particles were rare and, in this study, were never observed from a smoldering fuel bed.

Finally, some solid, angular particles were seen in the photographs. These ranged in size from less than 0.05 to about 20  $\mu\text{m}$ . These particles were very common from smoking fuel that had not yet produced flames (fig. 5) but were present in lesser quantities during all phases of fire activity. These particles did not adhere to filter media or to each other. Occasionally, a giant particle of this type did not remain on the impactor plate where it had been collected; this caused a small underestimation of the number of giant particles.

Comparison of photographs revealed that the preflaming smoking fuel bed released a high proportion of giant particles. The smoldering phase appeared

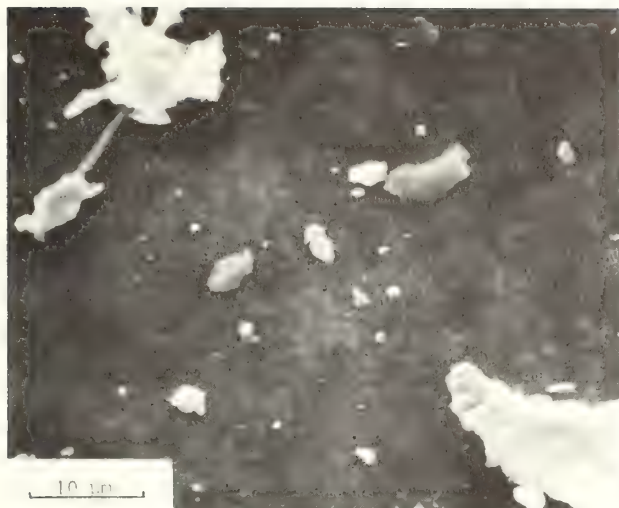


Figure 5.--Solid, angular smoke particles from preignition phase of burning Douglas-fir slash (SEM).

to have the highest proportion of submicrometer particles, but no particle count could be made.

The impactor was used to separate smoke particles at 5-, 1-, and 0.3- $\mu\text{m}$  aerodynamic diameters. The relationship of particle mass to fuel weight loss for each size class was calculated. The coefficients of variation between fires within series were high, from 0.30 to 1.43. The series of fires for which the flaming portion was sampled released 82 percent of the particulate mass in the submicrometer range. The smoldering period submicrometer fraction represented 87 percent of the mass. However, the variation was too high to make a statistically valid comparison between the emission behavior of different periods of the fire, or different intensities of burning.

The data from all 17 fires were pooled and weighted by the relative amount of fuel consumed by each. It was found that 8 percent of the total particulate mass is larger than 5- $\mu\text{m}$  aerodynamic diameter; 10 percent is between 1 and 5- $\mu\text{m}$ ; 13 percent is between 0.3- and 1- $\mu\text{m}$ ; and 69 percent is smaller than 0.3- $\mu\text{m}$ .

## SOURCES OF ERROR

Several possible sources of error were present in this experiment. The

fuel bed included only small limbs and twigs, to the exclusion of the large chunks, stumps, live fuel, needles, rotten logs, and forest floor present in any field burn. The interaction between wind and flames that causes erratic fire behavior on field burns was absent in the laboratory. It is possible that the higher local fire intensity, more powerful fluid dynamic forces, and the varied fuel bed composition in a field burn might increase the fraction of giant particles emitted.

The Andersen sampler used was designed as an ambient air sampler but was used here as a source sampler. The addition of an inlet sampling line probably increased the agglomeration of particles. Some impaction of giant particles occurred on the first jet stage of the sampler. This impaction systematically removed a small fraction of the very large (20- $\mu\text{m}$ ) particles.

Occasionally, a partially consumed needle, wood sliver, or bark fragment could be entrained in the plume and deposited on a filter. These particles would constitute only a fraction of 1 percent of the particulate matter sampled. Such particles would fall out very quickly. By chance, none were included on any of the impactor plates in this study, and their existence is mentioned here only as a possible source of error in future studies.



The weight of smoke particles in one size class collected from one fire was frequently in tenths of milligrams. Weighing errors could be as large as 20 percent in these cases. This was avoided somewhat by the accumulation of the smoke particles from several fires on one plate. Some slippage of the largest particles through the first collection plates occurred, allowing a small underestimation of the giant particles.

Errors due to non-isokinetic sampling and leakage and those caused by not compensating for temperature are thought to have been held to less than 5 percent.

## DISCUSSION

Electron photomicroscopy of particulate emissions from the laboratory burning of logging residues confirmed the existence of two basic particle structures. The most abundant particle was a smooth, spherical, submicron particle suspected to be condensed tars. These spherical particles ranged from smaller than 0.05  $\mu\text{m}$  to agglomerates of 80  $\mu\text{m}$ . There was a marked preponderance of particles of about 0.1- $\mu\text{m}$  diameter. The second basic particle group was polydisperse in size from infinitesimal to at least 20  $\mu\text{m}$  and did not tend to agglomerate.

Impactor separation of particles reveals that 82 percent of the particulate mass was in the submicrometer range, 69 percent with an aerodynamic diameter less than 0.3  $\mu\text{m}$ . The size distribution did not depend on fire intensity in the range sampled, as long as flaming existed. Smoldering fuel beds seemed to produce a higher percentage of submicrometer particles, but this was not demonstrated statistically. Samples collected from a smoking fuel bed before flaming started consisted almost entirely of giant, solid, angular particles.

An Andersen sampler designed for describing particle size distribution

in ambient air was found to be satisfactory but imperfect for source sampling. However, the sample inlet eliminated some giant particles and enhanced agglomeration.

In experiments to determine emission factors from forest fuels, isokinetic sampling is probably not a critical requirement due to the rarity of giant particles. Isokinetic sampling is generally thought to be important for particles larger than 3- $\mu\text{m}$  aerodynamic diameter.

The research reported herein measured particles only a few feet above the source. Additional sampling farther downstream might show a different distribution as hydrocarbons continued to condense, and particles agglomerated. A companion study could be accomplished by aerial sampling downwind from field burns, or within a duct system in the laboratory.

A multistage impactor seems to be a good tool for describing an aerosol with the wide range of sizes in slash fire smoke. However, a sampler specifically designed for source sampling would be better. At any rate, a separate sampler should be used to describe particles larger than 20  $\mu\text{m}$ . The sample line should be as short and as large in diameter as practical, to reduce agglomeration.

A dense emission of smoke just before flaming occurs in forest fuels is common. Further work with electron microscopy is required to confidently describe this aerosol, which seems to be unique.

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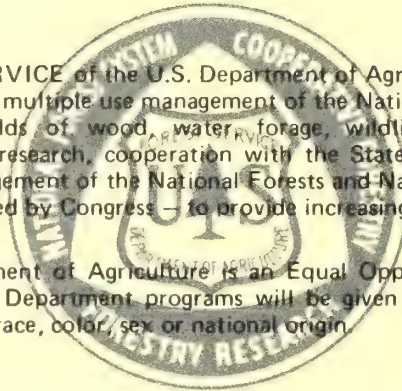
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